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Arecanut: India's Popular Masticatory — *History, Chemistry and Utilization*

To the Indians, Malayans, or the Indonesians, betel-nut chewing is as familiar as chewing gum to the Americans. In India the use of arecanut and its cultivation constitute a distinct agricultural practice scarcely less important than that of other economic crops, but little attention has been given to a proper assessment of the fruit either in India or elsewhere.

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Introduction

The subject of this communication is a tall palm commonly known as arecanut palm or betel-nut palm, bearing the scientific name *Areca catechu* Linn., and included in the tribe Areceae of the family Palmae. The palm owes its rating of importance to the fruits known as arecanuts or betel-nuts, which form the principal chewing material in India and in the far eastern countries. When the arecanut is employed as a masticatory, it is often associated in fresh or processed form with the betel leaf (*Piper betle* Linn.) and a little lime producing a deep wine red coloration in the mouth. Arecanut is almost symbolic of the great culture of some of the oriental nations, and to the Indians, Malayans, or the Indonesians betel-nut chewing is as familiar as chewing gum to the Americans. India shared the monopoly for this crop with the Strait Settlements and Ceylon until it was partitioned in 1947, when a large part of the arecanut tracts, particularly in Bengal, went to Pakistan. Since then there has been considerable activity on the part of the Government through the Indian Central Arecanut Committee, Kozhikode, to foster the production of arecanuts in the country especially by increasing the acreage under cultivation and obtaining higher yields from the existing gardens through improved methods of cultivation. This review is an attempt to stress the importance of this commodity crop, particularly in the light of certain recent contributions. In the preparation of this paper the published works on this plant have been freely drawn upon, but this does not by any means represent a mere compilation. On the contrary, effort has been made not only to evaluate the many observations critically and comparatively but also to indicate future lines of work which can be profitably pursued.

The arecanut essentially consists of a hard and fibrous outer covering commonly called the husk, enclosing within it the endosperm which is the edible nut. In India the use of arecanut and its cultivation constitute a distinct agricultural

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practice scarcely less important than that of other economic crops. Watt (151) referring to the cultivation and marketing of arecanuts in India writes, ". . . in Eastern and Northern Bengal and some portions of Assam its cultivation has assumed still greater dimensions. In certain districts of these provinces regular plantations of 5 to 20 or even 100 acres in extent occur (exclusively of betel-nuts) . . .". Its cultivation has proved to be of the greatest value from the commercial and industrial standpoint. He further states, "The magnitude and importance of the Indian production of betel-nuts may, however, be judged by the extent of coasting trade. . . . From the published returns of foreign imports and Indian production, . . . it would seem safe to affirm that the annual consumption of betel-nuts in India itself cannot be too far short of a valuation of Rs 225 lakhs, or say £1,500,000". However, it is apparent that the present production and consumption have exceeded many times the 1908 level, and arecanut has proved to be of considerable significance from the commercial and industrial standpoint, the import of betel-nuts now exceeding more than Rs 50,000,000 annually. In spite of the increasing economic importance of the fruit, little attention seems to have been given to a proper assessment of the fruit either in India or elsewhere, and for this reason arecanut has not been exploited to the same extent as coconut or other fruit trees.

History

Early History. The derivation of the name arecanut is not definitely known; it can possibly be traced to the Kanarese "adeke" or the Malayalam "adakka". In many other Indian languages the words "supari" or "tambul" refer to betel-nuts or to betel-nuts mixed with betel leaf and lime. In India arecanut has a long history as evidenced by a reference to it in early Sanskrit works under the name "Gouvaka" and by its prominence in Hindu mythology and religious observances.

The widespread occurrence of the habit of betel chewing is itself an indication of its great antiquity. In Somadeva's Katha Sarit Sagara there is a mention of betel-nuts flavored with five fruits. Reference to betel chewing is available both in the Jatakas and in several other Pali works as well as in Jain scriptures. In the Hitopadesa betel-nut is described as pungent, spicy, bitter, and sweet; it is also said to expel wind, to remove phlegm, to kill germs and to subdue bad odor, to beautify the mouth, to remove impurities, and to induce love. Sushruta has mentioned in the first century A.D. that after a meal, the intelligent eater will take either some fruit of an astringent, pungent, or bitter taste or chew betel leaf prepared with broken arecanut, camphor, nutmeg, or clove. Some of the early travellers who visited India mentioned the custom of betel chewing and the use of arecanut. Abd Allah Ibn Ahmad has paid a tribute to betel chewing in India in his treatise on drugs. He has quoted several Arab authors and mentioned Sheriff chiefly, according to whom "the betel brightens the mind and drives away the cares . . . whoever uses it becomes joyful; he has a perfumed breath and perfect sleep . . . betel-nut replaces wine among Indians by whom it is widely used". Chau Ju-Kua in 1250 A.D. spoke in his work on the Chinese and Arab trade of arecanut in Annam and of arecanut wine of the east coast of Sumatra. He has also mentioned Ceylonese kings making use of arecanut paste and pearl ashes; he spoke of arecanuts as one of the products of the Coromandel coast, Java, Borneo, and the Philippines (93).

The arecanut was first described by Herodotus in 340 B.C. The earliest his-

toric reference by a European to the habit of betel chewing among the orientals occurs in the writings of Marco Polo (1298). Subsequently Vasco da Gama (1498), Varthema (1510), Barbosa (1516), Garcia de Orta (1563), Acosta (1578, 1594), Abul Fazal (1590), Linschoten (1598), Francis Pyrard (1601), Roe (1615), Jacobus Bontius (1629), Bernier (1656–58), Boym (1656), Vincenze Maria (1672), Tavernier (1676) and Catchpoole (1703) have given similar accounts (68, 151).

Origin. The actual source of origin of arecanuts is, as in the case of many other crop plants, still a matter of speculation because of the many diverse views, but according to von Martius it is probably the Sunda Islands. Its cultivation is said to date back to the pre-Christian era. There is a reference to it in a Chinese work 'San-fu-huang' supposed to have been written during 140–80 B.C. under the name 'Pinlang', evidently a form of the Malayan equivalent of the fruit 'Pinang' (122). Garcia de Orta mentions it as being cultivated in Malacca before 1593, a fact later corroborated by Ridley (135). de Candolle (49) in his classical work on "The Origin of Cultivated Plants", quoting von Martius says, "Its country is uncertain, probably the Sunda Islands". Bretschneider's works indicate that the palms were found in the Malayan Archipelago and India in the first century A.D. Blume says that the habitat of the species is the Malay Peninsula, Siam, and the neighboring islands (21). The habit of the present system of betel chewing is mentioned in a work of the fourth century. The ancient Arabic writers seem to have recognized the importance of arecanuts and call it "Fobal" or "Fufal", referring to the habit of Indians masticating it with lime. Arecanut palms obviously growing wild in Malabar (India) have also been noted (21, 142). There has been no record of the fossil remains of the genus *Areca*, but the abundance of the palm genera discovered in the form of shells, leaves, and stems from the Tertiary period probably indicates that this genus was in existence as long ago as that time.

According to Beccari (19), the Philippine Islands were the original home of the arecanuts; he has described from this region various forms of *Areca catechu* occurring closely allied and presumes that it was in the Philippines that the edible variety finally assumed its present specific characters. Favoring the greater antiquity of the species in the Philippines, Beccari argues that in no other part of south or east Asia is any species found which in any way approaches the cultivated variety. *Areca catechu* var. *sylvatica* probably represents the wild variety of *Areca catechu* Linn. However, the large number of varieties of arecanuts described from Malaya seems to suggest that the species originated in Malaya. This is also supported by the fact that the largest type of arecanuts (*Pinang wangi*), decidedly one of the important types which is almost on the verge of extinction, is described from Malaya. Indeed, arecanut has been a source of trade between India, Ceylon, Indonesia, and Malaya from the remotest periods of history (63).

Distribution. Arecanut palm is essentially tropical, its distribution being confined to the southeast Asian countries like India, Pakistan, Ceylon, Malaya, the Philippines, and Japan. These countries form the main belt of arecanut cultivation in the tropics. Arecanuts are also reported to occur in Indo-China (114), East Indian Islands, and southern China (72), Formosa (156), Arabia (22, 29), Egypt (142), and Java (94). Ridley (135) reports its occurrence northward as far as Canton, Amoy, Formosa, and the Bonin Islands, westward as far as Socotra, Madagascar, and East Africa, and east-

ward in the central Pacific and lately in Fiji. The arecanut palms are also found in cultivation in certain areas of the Persian Gulf and Zanzibar and as an ornamental in some warm regions, especially Florida and Hawaii (135, 60, 10, 109). Whether the palms are indigenous to these regions still remains undetermined because of their restricted occurrence and the absence of any wild species. It might be that during Tertiary times the species was distributed throughout the world; in the later periods the continuous distribution of palms was disturbed because of still uninvestigated factors. A large number of genera and species disappeared from the tropics of the hemisphere, leaving only isolated types in the protected areas, or the fortuitous dissemination of the fruits by man principally for mastication is also a highly probable factor for the wide distribution of the species.

The range of distribution of the species in India appears to be restricted and is chiefly confined to the southwest coast, Mysore, Coorg, Bombay, Bengal, and Assam, the palms being conspicuously absent from upper and central India. Statistical data concerning the cultivation and production of arecanuts in India are far from satisfactory. According to information supplied by the Indian Central Arecanut Committee, the total area under cultivation of arecanuts in India in 1956 was 2,161,500 acres with an annual output of 21.76 lakhs of maunds of arecanuts.

Biology

Botany. *Areca catechu* Linn. is one of the species of the genus *Areca* established by Linnaeus. Four species, namely, *A. catechu* Linn., *A. concinna* Thw., *A. triandra* Griff. and *A. nagensis* Griff. are indigenous to India, but a few other species like *A. madagascariensis* Mart. (= *Chrysalidocarpus madagascariensis* (Mart.) Becc.) are grown in gardens as ornaments (69, 59, 90). The edible arecanuts belong exclusively to *A. catechu.* In Ceylon, however, the fruits of *A. concinna* are reported to be occasionally chewed as a substitute for arecanut (89). There are no widely divergent and distinct morphological types of arecanut palms, although there are differences in size and shape of the fruits and such other characters by which types or varieties of fruits are distinguished. The fruits of the palms in different regions and on different trees in the same region exhibit variation in size, and on this basis the palms have gained

TABLE 1

TYPES OF ARECANUTS DESCRIBED FROM DIFFERENT COUNTRIES

India	Ceylon	Malaya	Philippines
Round big, Round small, Convex shaped, Pointed top, Narrow base, Long (3, 136). *A. catechu* var. *deliciosa* (132), Big oblong, Large oblong, Big round, Apex round, Long, Small ellipsoid, Small oblong, Small apex pointed, Small round (121).	Sinhalapuwak, Ratapuwak, Himbapuwak, (97, 100). *A. catechu* var. *alba* (110).	Pinang wangi, Pinang telor, Pinang jambu, Pinang lemak, Pinang kuning, Pinang betel, Pinang malan, Pinang bentotabon, Pinang small round, Pinang ranggong, Pinang selung, Pinang rambai, Pinang kerdu (64, 101, 136).	*Areca catechu* forma *communis*, *A. catechu* var. *sylvatica*, *A. catechu* var. *longicarpa* (19), *A. catechu* var. *batanensis* (27).

specific or varietal status from some botanists. The different types of arecanuts are normally seedling races which breed true to seed except for some simple fluctuating variations. It is said that more delimitations. The types of arecanuts described from different countries are summarized in Table 1. They are mostly based on the size of the fruits (Fig. 1); this delimitation is somewhat

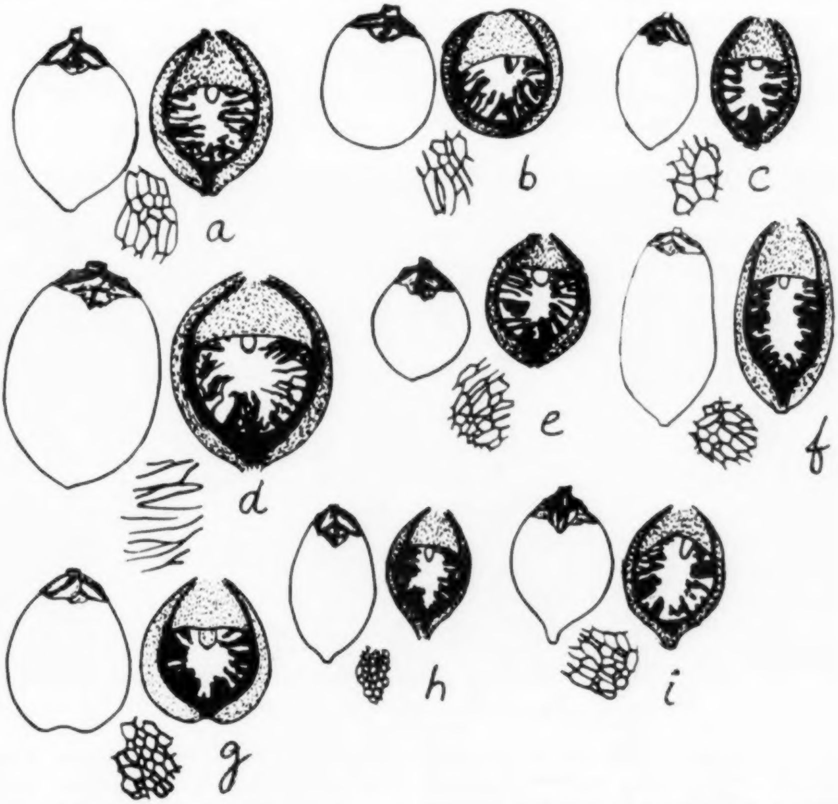

FIG. 1. Types of arecanuts. Each group represents outline of the fruit, vertical section of the fruit and pattern of network on the surface of the nut. (a) Big oblong; (b) Big round; (c) Small oblong; (d) Large oblong; (e) Small round; (f) Long; (g) Apex round; (h) Small ellipsoid; (i) Small apex pointed.

than seventeen varieties of arecanuts are known in India itself (11). The names of the types of arecanuts given by the local population based on the size and shapes of the fruits and even on the degree of astringency of the kernels are often unreliable for specific or varietal arbitrary, but the nomenclature is convenient and widely used.

The morphology of the arecanut palms and the variations in the types of arecanuts have been described by different workers (3, 21, 69, 100, 121, 136, etc.), and hence only their salient features

along with notes on their ecological anatomy will be considered here.

Arecanut palms are tall and erect with typically unbranched stems (Fig. 2), attaining a height of 12–30 meters and a diameter of about 30-45 cm. The palms terminate in a crown of long graceful pinnate leaves, which are normally bright green but which on aging turn golden yellow and finally brown. Like all other monocotyledons the arecanut palm has only a terminal bud and lacks a cambial cylinder. Branching of the arecanut palm is rare, but a few cases of fasciation of the top have been noted (48).

The stem is greyish brown, generally with epiphytic growths of lichens, and is ornamented with scars of fallen leaves in a regular annulated form. The stem possesses great mechanical flexibility. The epidermis of the stem in the early stages is covered with a heavy layer of cuticle, but in the older stems this layer together with a few of the hypodermal cells becomes thick-walled and forms a distinct layer resembling a periderm, characteristic of the dicotyledons. The periderm-like layer peels off easily in mature stems exposing the hypodermis which become reddish by this time. In the younger stages the hypodermal cells contain abundant chloroplasts. Vascular bundles are numerous and typically monocotyledonous. The ground tissue consists of symmetrically arranged rows of cells which form a sort of spongy network toward the center of the stem with small air spaces.

FIG. 2. A good arecanut garden in Malabar (India).

The arecanut palm has a fibrous root system. A mass of thick adventitious roots, each 0.60-1.25 cm. in diameter, arises from the base of the stem about 30–45 cm. below the ground and spreads into finer branches ramifying in all directions. In some the mass of roots is seen as a tuft above the soil at the base of the stem. The arecanut root has a structure adapted for growth in very moist soils. Outside the central portion of the root enclosing the main conduct-

ing tissues there is a large extra-stelar peripheral region filled with vertically arranged air spaces. Thick-walled stone cells are distributed in the cortex and the pith.

The leaves of the mature palm are large, 0.9–1.5 meters in length. The leaf has 20–30 pinnae, 0.6–0.9 meter in length; the basal region of each leaf forms a broad sheath which encircles the stem and forms a protective covering for the developing inflorescences until a few days prior to ripening. The structure of the leaf as a whole appears to be xerophylous due to the presence of bands of sclerenchyma in the mesophyll and the thick cuticular covering of the epidermis. The stomata are small and distributed on the ventral surface. The conducting veins are also numerous and show strong xerophylous adaptations.

Detailed studies on the morphological and floristic characters of the arecanut palms bearing different types of fruits have shown that the palms are strikingly similar showing no indication of a varietal distinction except in the size of the fruits. A statistical study of the height, circumference, and related features of the palms bearing different types of fruits has also led to the conclusion that the species as a whole is homogeneous, showing no appreciable differences in its vegetative and floral characters from which types can possibly be demarcated (119). Further, such characters of the palm relating to their vegetative development appear to be influenced by the ecological features of the locality rather than by the phylogeny of the types. Sands (136) in this connection writes, "As observations on the flowering of betel-nut palm have shown that the flowers are normally cross pollinated and that in all plantations and gardens there are numerous types, it will be realized that in the absence of breeding experiments, it is an almost hopeless task endeavoring to decide which of the large number of forms are distinct varieties or races and which are merely unstable hybrids . . .".

Raghavan and Baruah (121) have published a descriptive list of the characters employed by them to describe the types of arecanuts from Assam. Several growth and structural characters of arecanuts are relatively reliable in classifying and identifying the types. The nature of the rumination of the endosperm, the pattern of the network on the seed coat, and the range in proportion of the husk and the endosperm are regarded as relatively constant for identification purposes. Certain of the inflorescence characters, namely, color of the emerging inflorescence, nature of the inflorescence axis, and taste and degree of hardness of the kernels have also been used by some to determine a particular type (50, 132). The types may differ in the color of the mature fruits. Differences have also been noted in the maturity of the palms, some bearing early and others late. Work on the morphology of the pollen grains (120), anatomy of the fruit stalks, and the cytology of the different types (119) have further given a clue to the understanding of the probable genetic status of the types of arecanuts occurring in nature. The pollen grains of the types show a similar morphology in having monocolpate grains. The anatomy of the fruit stalk shows that all the types are similar with minute variations in the frequency of occurrence of the bundles and length of the vessel elements, whereas the types show a similar chromosome number, all having $2n = 32$, with minute differences in the length of the chromosomes and position of the constrictions. It has thus been apparent that the range of variation in *Areca catechu* is limited in so far as there are many types with border-line affinities and, therefore, standing at the same level of evolution. In view of the minute cytological changes delimiting the

types, it is possible that the types of arecanuts existing today have originated from the ancestral ones through gene mutations. Furthermore, the compatability between the types being very close due to the close similarity in their karyotypes, hybridization occurring freely in nature induces the production of new types. This seems to be supported by the fact that arecanut palms bearing the different types of fruits occur freely intermixed in the plantations, thereby giving opportunities for cross pollination between the types (119). The exact status of the types can, therefore, be ascertained by intervarietal crosses in the field; such studies offer ample scope full of potentialities in the evolution of vastly improved types of arecanuts.

Floral Biology. The arecanut palms are monoecious, male and female flowers occurring on the same spadix. Young trees during the first few years of their bearing do not possess any female flowers and yield no fruits; similarly some of the older trees do not bear any inflorescences at all in some years. A full grown spadix of arecanut produces on an average 250 to 550 female flowers and 2,000 to 3,000 male flowers, the former being confined to the basal region and the latter forming the filiform panicles of the spadix. The inflorescence (Fig. 3) is formed in the axil of each leaf on a mature tree and is enclosed in a spathe which splits open to expose the flowers. The spadix is composed of a transversely compressed main axis about 30 to 60 cm. in length which bears some 20 to 25 secondary branches. The latter in turn form the tertiary branches. In certain cases bisexual flowers have been recorded; they occur on the same rachis between the male and female flowers (126). Usually the female flowers are confined to the base of the rachis or occasionally to the end (108); or sometimes, a male flower may be found adjoining a female flower. Each female flower has two whorls of perianth, the

FIG. 3. Inflorescence with young fruits (buttons).

outer boat-shaped green whorl of sepals and the inner petals. The ovary is ovoid-globular with a dome-shaped tip formed by the three stiff stylar projections. The whorl outside the ovary is formed of six staminodes which are closely appressed to the ovary. The male flowers are minute, cream-colored, triangular structures, comprising two whorls of perianth, six stamens, and a central pistillode. However, the male flowers in some of the spadices exhibit varying degrees of abnormality which have been described by Raghavan (118). Both the male and female flowers are very fragrant.

Megasporogenesis and the events leading to fertilization have been investigated by Swamy (141) and Rao (129, 130). Development of floral organs of both male and female flowers is acropetal. They arise as follows: sepals, petals, stamens or staminodes, pistil or pistillodes. The ovules are amphitropous until fertilization and later become anatropous. They are crassinucellate and bitegminous. The outer integument is massive and is traversed by branching vascular bundles. Soon after fertilization the outer integument sends off folds of ruminations which grow centripetally though they never meet in the center. These form the characteristic lamella of the endosperm, giving them a marbled appearance in section. The development of the embryo conforms to the 'Onagrad' type of Johansen (131).

The male phase of the arecanut palms begins as soon as the spadix frees itself from the spathe. The flowers commence to open indiscriminately, and this phase is continued for two to four weeks until all the male flowers are exhausted. The individual male flowers open early in the morning and remain in that position until they wither in the evening, maximum dispersal of pollen grains occurring between 9 and 12 A.M. There also appears to be an optimum period during the first eight to ten days after opening of the spadix when the maximum discharge of pollen grains is effected (119).

At the close of the male phase, the green petals of the female flowers lengthen and change their color to yellowish-white. The petals slightly open at the tips, and soon after the receptive trifid stigmas are open to pollination. The female phase generally lasts for four to five days, and the flowers remain open during this entire period exposing their receptive stigmas. The surface of the stigma is constituted of a special kind of thick-walled palisade cells which are closely packed in the young flowers but become club shaped and elongated at maturity of the flowers leaving interspaces between them for the reception of the pollen grains. It is thus evident that the male and female flowers never open simultaneously thus necessitating cross pollination which is generally effected by wind. Bees and insects regularly visit the male flowers, but they have not been seen on the female flowers; their role in pollination is, therefore, doubtful. It is noted, however, that some palms develop spadices in such quick succession that the male phase of the freshly opened spadix overlaps the female phase of the one preceding it, so that self-pollination is possible. Cross-pollination, as already noted, effects considerable variation in the progeny and induces production of new types (136, 138).

It is observed that all the female flowers that are borne on the spadix do not set fruits, a considerable majority of them falling off prematurely. The extent of sterility caused by such flower fall in some of the plantations in Assam (India) has been estimated to vary from 35 to 55 percent (120).

The reasons for the low fruit-set in relation to the large number of female flowers produced in each spadix are primarily due to: (1) non-uniformity in the time of maturity of the male and

female flowers with considerable lag between, (2) differences in the proportion of the sterile pollen grains in the male flowers, (3) failure of a considerable number of pollen grains to germinate on the stigma, (4) slow growth of the pollen tubes and their subsequent death inside the stylar canal resulting in failure of fertilization, (5) short life of the pollen grains and the degree of receptivity of the stigma being most favorable when the flowers are slightly open, (6) conditions of temperature, humidity, and other factors which affect the successful dispersal of the pollen grains and their subsequent germination, and (7) association of air-spora originating from fungi, bacteria, and actinomycetes with pollen grains in the plantations and its effect on the subsequent process of pollination and fertilization (120, 13, 14).

From the foregoing it is evident that lodging of the pollen grains on the stigma under natural conditions and its subsequent germination and growth leading to the fertilization of the ovule are important factors controlling fruit-set in arecanut palms. Ordinarily, not more than 75% of the female flowers actually receive pollen grains on their stigmatic surfaces. The main problem, however, resolves itself in the active growth of the pollen tubes inside the stylar canal leading to the fertilization of the ovule. The failure of the pollen tubes to fertilize the ovules has been due to the length of the pollen tubes formed being inadequate to reach the ovule, the length of the style of the female flowers generally varying from 0.8 to 1.3 cm. Detailed field studies on the problem conducted in Assam have indicated that various fungi like *Aspergillus*, *Penicillium*, *Actinomycetes*, and bacteria colonize the stigmatic surfaces of arecanut flowers during the early days of their opening; the subsequent growth of the pathogens on the stigma releasing toxins into the stylar canal greatly inhibits successful germination of pollen grains and growth of the pollen tubes (14). This phenomenon of antagonism would be of considerable significance in determining the factors that can check the large amount of fruit loss in arecanuts. Experiments on the germination of pollen grains *in vitro* in cultures using various synthetic auxins, vitamins, and trace elements have also indicated that the percentage of germination of the pollen grains and the rate of growth of the pollen tubes can be enhanced to a considerable extent (123), but the practical application of the results still remains to be assessed in field trials.

Agronomy

Soil. The type of soil in which the palms are grown is important for best production of the crop, but it is not a limiting factor because arecanut palms grow in many kinds of soils varying in texture from laterite to loamy types. In India the largest areas under arecanut cultivation occur in the laterite soils of Mysore and Kerala, although generally in laterite soils the palms do not grow well unless compensated by heavy manuring. In Fiji the palms are found in the alluvial soils of the coastal areas, while in Malaya the crop is cultivated in a wide range of soils from granite to limestone and calcareous types; these soils are generally considered poor in plant foods (101). A good crop of arecanut can be raised in nearly all types of soils provided they have a capacity for thorough drainage and ability to retain optimum moisture required by the palms. Light and sandy soils are not suitable unless copiously irrigated and manured.

The cultivation of arecanut in the Bombay State is chiefly confined to the coastal areas which consist of sandy soil with an admixture of laterite loams. In Mysore, especially in the Malnad regions, most of the arecanuts are grown

in laterite soils of loamy and clayey character. In West Bengal the soil is of alluvial formation with large admixture of sand or light loam, whereas in Assam the soils are of a sandy loam type. They are fairly rich in nitrogen and generally low in available potash and phosphate. In Assam the presence of lime in certain soils appears to be a limiting factor for proper growth and good yield of arecanuts (119).

Climate. The arecanut palms thrive in regions of high rainfall (200 inches or above); they can also survive on as little as 30 to 60 inches of rainfall if the ill effects of low rainfall are compensated by copious irrigation in summer. More important than the rainfall are the drainage facilities and the seasonal distribution of rainfall. For good remunerative yield in arecanut gardens the important factors are a uniform distribution of rainfall, good retentive capacity of soil, and irrigation when necessary. Investigations on the comparative yields of arecanuts in different places in Assam have shown that the output at Cherrapunji is poor, the soil here being surprisingly low in moisture-retaining capacity, despite the fact that the annual rainfall here is great (119).

In arecanut plantations the maximum temperature should not exceed 100° F., but a continuous temperature of 60° to 100° F. is preferable. The ill effects of summer temperatures are compensated by profuse irrigation. The palms are unable to withstand extremes of temperatures and wide diurnal variations. They are tolerant to moderate elevations on mountains but generally thrive best at low altitudes.

Arecanut is a shade-loving plant and is usually grown as a mixed crop with fruit trees such as mango, jack, guava, orange, plantain, coconut, etc. (Fig. 4). Subsidiary crops like cardamom and pepper (Fig. 5) are also cultivated in gardens in Mysore (5). A mixed plantation is said to cool down the atmosphere which is so essential for the palms (3); however, it is possible that the presence of a large number of fruit trees in a garden subjects the crop to competition, thus reducing yield (119).

FIG. 4. Coconut and plantains as border crops in arecanut gardens.

Propagation. Arecanuts are exclusively propagated by seeds. Selection of the seed nuts is the first step in producing a profitable crop of arecanuts. In south India, seed nuts are gathered from about 30-year-old trees or from young trees. In Assam and Bengal no importance is attached to the matter of selection of seed nuts for planting. They are collected from all trees irrespective of age. The Malayan growers also follow a similar method in the selection of seed nuts. Even in the matter of selection of the particular bunch from which the seed nuts are later gathered, the methods followed in the different parts of India vary considerably. It is a custom in many places to fix up the middle bunch for seed purposes, while in certain areas the last bunch of the season is preferred. The seed nuts are allowed to ripen completely on the tree and are dried in the

sun for one or two days or in the shade for three to seven days before being sown. However, drying of the nuts does not increase their capacity for germination (3, 138, 83).

No elaborate preparatory land tillage is, as a rule, necessary for raising the seedlings. Generally, well-tilled land in a well-drained area in the garden or on the sides of the irrigational channel forms a good bed for sowing the seeds. The seeds are sown in rows 15 to 22 cm. apart or in groups of 20 to 50 seeds in pits deep enough to cover them but shallow enough to permit the young plants to reach the surface of the soil (Fig. 6). Since the harvesting seasons in the different states in India vary, the time of seeding also varies with location and weather conditions. In many gardens a large number of seedlings sprout from naturally fallen nuts which are allowed to grow in situ into adult palms. The rate of growth of the seedlings depends upon the after-care bestowed on them. Recent studies on the merits of different nursery practices in arecanut cultivation have shown that sprouting the seednuts in loosely tied straw bundles and then planting them in nursery beds gave low germination (84.5 percent) and poor establishment in the nursery (76 percent). Direct sowing in the nursery gave 95 percent establishment; seedling growth was stronger after direct sowing than after transplanting and in earlier germinated ones than in late germinated ones (16, 17). The husk is sometimes artificially rotted to facilitate germination.

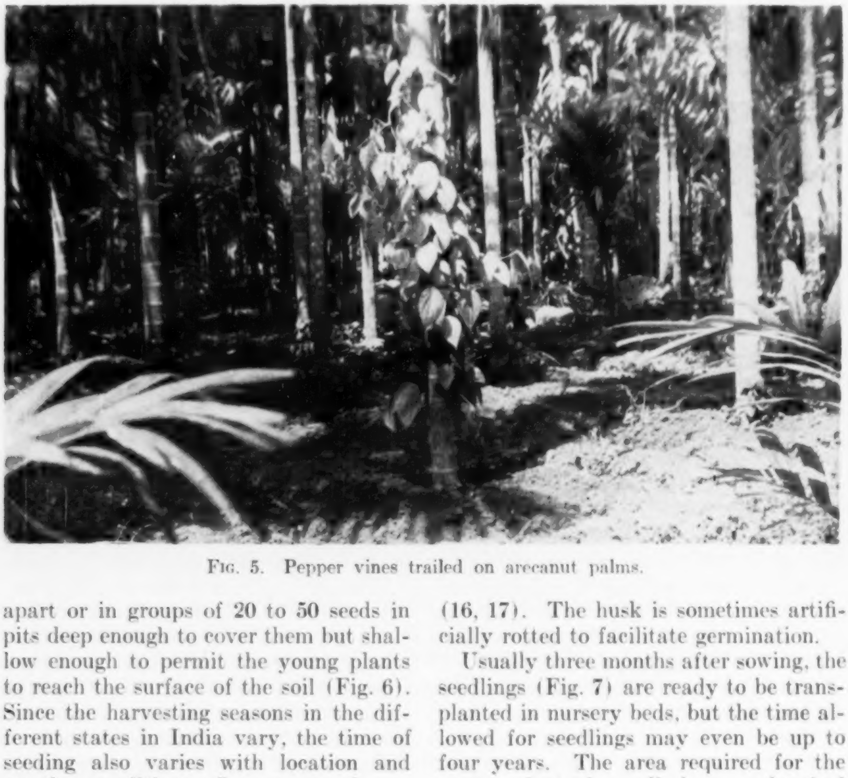

FIG. 5. Pepper vines trailed on arecanut palms.

Usually three months after sowing, the seedlings (Fig. 7) are ready to be transplanted in nursery beds, but the time allowed for seedlings may even be up to four years. The area required for the nursery is to be well dug or ploughed and a shade crop of bananas planted about 2.7 meters apart in the north-south direction. Planting of banana suckers may be taken up prior to planting of the seedlings so that they may be-

come well established and give sufficient shade for the young palms. Watt (151) has reported that in Bengal in the earlier stages of plantation, *Erythrina indica* Linn. is planted for shade. The interspaces between the banana rows (3.6 meters apart) are to be thrown into raised beds 1.2 meters wide and 15 cm. high and of a convenient length in the north-south direction. Two nursery beds each 1.2 meters wide will run between the two banana rows with a central drainage-cum-irrigation channel of 45 cm. width. To supplement the shade of the bananas, legumes like *Sesbania* may be sown in the western margin of each nursery bed (111).

The young seedlings are to be planted in the nursery beds at a distance of 30 × 30 cm., and in each bed three rows of plants can be planted leaving 30 cm. margin on either side. Spacing in the garden is a matter of choice, but about 400 to 600 trees per acre is usual. After about 20 years the older unproductive trees in the garden are replaced by fresh seedlings. Thus, some of the older gardens may often have 800 to 1200 trees per acre. After the seedlings have been planted, the beds are to be mulched with green or dry leaf, cattle dung, wood ash, or ground nut cake according to the demands of the local conditions. Beds are to be made only in the rainy season and should be well irrigated in summer.

FIG. 6. Young seedlings in seed bed.

Cultural Practices. No systematic study of the cultural practices generally necessary in arecanut plantations has been undertaken either in India or elsewhere. Hoeing the garden, weeding, and intercultivation are some of the more important operations attended to in south India.

No attempt has been made to determine the manurial requirements of arecanut palms under controlled cultural conditions. In the Malnad region of Mysore, ten cwts. per acre of farmyard manure is applied yearly, and a mixture of ground nut cake is applied once in

three years. Ammonium sulphate, superphosphate, and potassium sulphate have also been found to be beneficial. Leaf and green manures are used frequently (153).

Flowering. Under average conditions the palm flowers in about the seventh year, reaching its full bearing potential in about 10 to 15 years. Given the best conditions, the palms start to bear even in the fourth year. In the different arecanut growing regions in India there are well-defined flowering seasons and corresponding harvesting seasons. The fruits take about six to eight months to ripen. In the younger stages they are green and at maturity gradually change from green to orange-yellow or scarlet red. The economical life of the palm in India is considered to be 45 to 70 years.

Harvest. The arecanuts are generally harvested when they are ripe and are bright red; this, again, is a matter of choice to suit the requirements of the particular market. Shedding of a few nuts in a bunch is a sufficient indication that it is ready for harvest. Because of the tall and slender nature of the palm, harvesting of arecanuts is a process which calls for considerable skill and dexterity, and often primitive methods are employed for the purpose. On the southwest coast of India there are special classes of people who can climb the palms at a fast rate. Not uncommonly, in closely planted gardens, the laborers manage to swing from the top of one tree to another without coming down, thus harvesting a number of trees at a stretch. In certain places in India and in Malaya a long bamboo pole with a sharp sickle attached to it is used for harvesting purposes. The use of trained monkeys for harvest is also a common feature in Malaya (100, 101).

Yield. Each tree on an average yields two to three bunches per year, each containing about 150 to 250 fruits (Fig. 8). These figures vary easily one way or the other, for they depend on numerous fac-

FIG. 7. Arecanut seedlings having different tones of color.

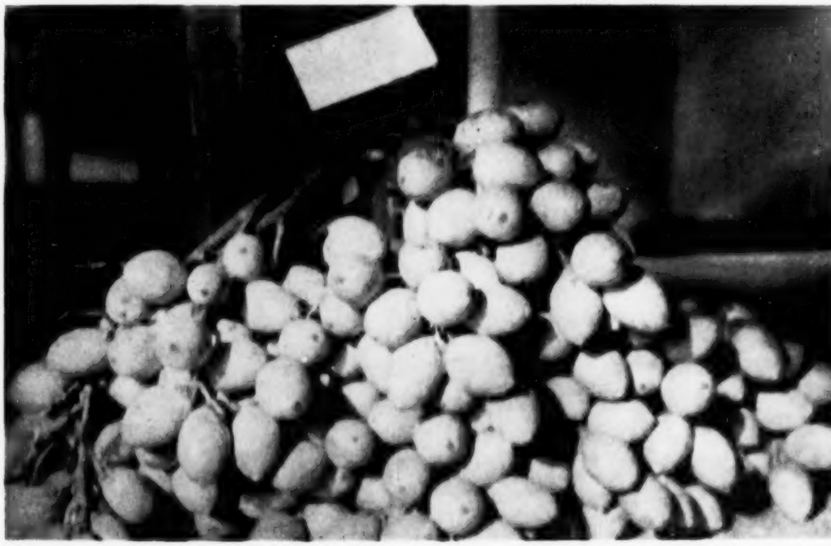

FIG. 8. A good bunch of arecanuts.

tors that operate jointly or separately. In certain large types the yield may vary from 50 to 100 fruits per bunch, or more commonly the small size of the nuts in a bunch is compensated by their large number. The yield of arecanuts in the different states of India on the basis of information supplied by the Indian Central Arecanut Committee is as follows:

State	*Area in acres*	*Yield in Mds.*
Kerala	1,49,400	10.06
Mysore	73,100	7.79
Assam	25,500	2.30
West Bengal	5,500	0.50
Bombay	5,000	0.56
Madras	3,000	0.25

Diseases and Pests

Fungal Diseases. Like many other crop plants, arecanut also has its share of fungal and insect pests, many of which have not been adequately investigated. Among the fungi responsible for diseases the most important is *Phytophthora arecae* (Col.) Pethy, which causes the "Koleroga" (fruit rot) disease of the arecanut palms. More than two strains of the pathogen are reported to be parasitic on the palms (128). It is possible that the disease was in existence for a very long time, but in India it appeared in an epidemic form only about 40 years ago in western peninsular India. It has also been reported recently from Assam (98). The havoc caused by the disease may be judged by the fact that it usually reduces the yield to less than 75%.

The "Koleroga" usually appears two to three weeks after the onset of monsoon. The fungus attacks the fruits when they are still green. The spores germinate on the moist surface of the green nuts and penetrate the tissues of the husk and the fruit stalk, thereby weakening the attachment of the fruits resulting in their fall. Fallen fruits have a felty white mycelial mass on their surfaces which soon covers the whole fruit. Alternate warm and damp spells as well as close

planting of trees in the garden favor multiplication of the spores and spread of the disease. If the activity of the fungus goes unchecked, the disease spreads into the central shoot and finally causes the death of the tree in about two to three years (100).

The most effective method of controlling the disease is by spraying Bordeaux mixture with or without an adhesive (3, 43, 92); the entire operation, however, appears to be somewhat difficult because of the nature of the palm. Recent investigations have proved that the crown of the palm harbors latent infection during the warm periods without showing any external symptoms whatsoever. These plants later become a potent source of infection of other trees during the ensuing monsoon when enormous quantities of sporangia are produced and disseminated (98). Elimination of trees that harbor latent infection and spraying of the affected palms to localize infection are methods employed to check the spread of the disease. The areca growers in Mysore (India) protect the bunches of fruits during the rainy season by an improvised covering of leaf sheath or dry grass. This is supposed to prevent the contamination of fruits by the fungal spores; the operation is laborious and costly and of doubtful utility for large-scale trials (100).

In Mysore the arecanut is also subject to a disease called "foot rot", locally known as "anabe", the causal organism being *Ganoderma lucidum* (Leys.) Karst. Butler (30, 31) refers to this disease as the 'betel-nut plague in Sylhet' apparently caused by *Fomes lucidus*. The first reference to this disease is by Coleman (42). The symptoms of the disease have been described by Watt (152), Butler (30), Rau (133), Venkatakrishniah (145), and Venkatarayan (146) and are akin to those of drought. There is at first a drooping or yellowing of the lower leaves, not infrequently followed by a reduction in size of the crown which subsequently dries up. Butler (30) states that one of the earliest symptoms of the disease is dropping of the nuts. The fungus later affects the interior of the stems and is marked outwardly by minute holes on the stem which exude a gummy secretion. This is subsequently followed by the roots becoming brittle, discolored, and dry, the final external symptom being the appearance of characteristic leathery, disc-like outgrowths called "anabe". The affected palms eventually dry up and die. The diseased palms on examination show a dark brown color inside and emit an unpleasant smell.

No proper remedial measures have been adopted for this disease. The local cultivators eradicate the infected palms by applying sulphur at the root, they isolate the attacked trees by putting them in trenches filled with lime, or they burn the diseased trees. However, these methods are presumably only partial remedial measures (100). Two brands of tree killers, "Globe" and "Borgia", are reported to have given promising results in easily eradicating the infected plants (145).

Other fungi that cause diseases on arecanut palms are *Gloeosporium*, which attacks the husk and the fruits causing brown spots, and *Thielaviopsis paradoxa* von Hon., which causes lengthwise splitting of the stem not uncommonly followed by exudation of colored sap (100). The stem is also reported to be attacked by *Polyporus ostreiformis* Berk., *P. zonalis* Berk. and *Lenzites striata* Swarts (82). Bud rot disease similar to that observed in coconut or palmyra palms has also been found in arecanut palms. The diseased trees show an internal injury in the crown in the form of a longitudinal cut confined to the greater portion of the bud with no symptoms of outside injury. The inflorescences, as they are formed, are also attacked. The subsequent de-

cay of the bud is enhanced by secondary infection by *Fusarium* sp. and bacteria (**143**, **147**). In West Bengal, Nambiar and Sreenivasan (**103**) have reported seedling blight caused by *Phomes* sp. and *Colletotrichum catechu*. A storage disease of betel-nuts caused by *Aspergillus niger arecae* has been described by Lal and Chandra (**88**).

The incidence of stem splitting and breaking disease is also widespread in arecanut plantations. Exposure to the hot afternoon sun and the consequent scorching of the tender portions of the palms are the prime causes (**127**). Further damage is caused by the invasion of the affected tissues by more than one species of wound parasitic fungi such as *Ceratostomella paradoxa* (**140**), *Ganoderma lucidum*, *Lenzites sp.*, *Polystichus sp.* (**127**, **148**), and *Dadaelea sp.* (**104**). Provision of adequate shade for the palms is reported to be the best method for preventing the incidence of the disease (**127**). A disease condition characterized by cracking of the fruits is also known (**18**).

Physiological Diseases. "Band", locally known as "Hindimundigae" in Mysore, is a widely prevalent disease in certain parts of Bombay and Mysore. The symptoms of the disease are reduction in the size of the internode and tapering of the stem below the crown, followed by the appearance of the leaves and leaflets in a bush-like form in advanced state of the disease. This is also associated with a darkening of the leaves which acquire a leathery feel. Although the causes of the disease are still not established with certainty, it is presumed that the soil in which the band-affected palms are growing is deficient in some of the trace elements or micronutrients (**74**). For this reason treatment of the affected palms with copper sulphate and lime along with organic manure has given encouraging results in the control of the disease in Bombay Presidency. Manganese and iron toxicity due to the abnormally high absorption of these ions by the palms has also been suggested as a probable cause of band disease (**45**).

Other diseases caused by nutritional deficiency or allied factors are only of local importance, and no satisfactory remedial measures have been adopted for them. Among these the stem-breaking disease is important. The symptoms are manifest in darkening of the stem and yellowing of the lower leaves. Subsequently, the stem loses its turgidity and shape and finally cracks and separates. The precursors of the disease are still imperfectly known, and it is presumed that certain environmental conditions prevailing in the area—high rainfall, absence of soil drainage, overcrowding of the palms, and lack of essential elements—are contributory causes for the diseased conditions. Root and leaf diseases similar to that in coconut have also been noted in arecanut palms (**100**).

Pests. There is no record of any serious damage on arecanuts by insect pests during any stage of its growth; however, rhinoceros beetle (*Orcytes rhinoceros*), leaf eating caterpillar (*Nephantis serinopa*), borer (*Arceerns fasciculatus*), white ants, and a number of other insects and mites, notably *Icerya aegyptiaca* Doughal, *Rodolia sp.*, *Leucopholis lepidophora* Blanch are said to cause minor damages in certain areas of Mysore and in Malaya (**100**, **101**, **115**). The Acridian *Valanga nigricornis* Burm., has been recorded as feeding on leaves in Malaya. Numerous Coleoptera, Rhynchota, Thysanoptera, and the ant, *Plagiolepis longipes* Jud., have been found feeding on the inflorescences (**64**). Squirrels, rats, and monkeys may cause damage.

A disease prevalent in Kerala is "Chovakedu". The symptoms are yellowing of the leaves and shedding of both tender and mature nuts. The endosperm of such fallen fruit presents a

black appearance and is soft to touch. The disease is due to infestation by different species of mites; spraying the trees with wettable sulphur, "Folidol", or lime and sulphur is advocated as an immediate measure to check the disease (**84**).

Processing

The following discussion on the preparation of arecanuts for the market will be limited primarily to the procedures adopted in India, although certain differences in other countries will be pointed out.

Arecanuts are consumed in India either raw or cured. In some places, as in Assam and in the West Coast, no curing or processing methods are in vogue, and ripe nuts are masticated during the harvest season. The surplus of the nuts is stored in pits in the soil or in water in earthenwares for a period of five to seven months. During the off-season they are taken out and chewed. In South Kanara (Mysore), ripe nuts are collected, dehusked or cut into two, dried and marketed without shells. Sometimes ripe nuts are dried in the sun for six to seven weeks and marketed as such (Fig. **9**). In Indian markets these nuts are known as "Chali" nuts. In Malaya also the arecanuts are marketed after similar treatment, the products being known variously as "Pinang blah", "Pinang kossi" or "Pinang salai" or "Pinang awak", depending on whether the nuts are dried, unsplit, or split or whether they are sun-dried or oven-dried. When perfumed by the smoke of benzoin, they are "Pinang ukup" (**101**, **28**). Dried nuts in Malaya are marketed as "Pinang bunga" or "Pinang kasar". Ripe whole-dried nuts are also exported from Ceylon under the name "Karunka" or "Kotta puwak" (**97**).

Processing of the immature nuts is a costly and laborious operation and is undertaken on a commercial scale in

FIG. 9. Husking of dried arecanuts.

Malabar and Mysore. Processing is to improve the color, taste, palatability, and keeping quality of the nuts. In Mysore where traditionally the best processing methods are employed, the fruits are collected when they are nearly three-fourths ripe. The selection of nuts of the correct stage of maturity is important in so far as any deviation on either side badly affects the quality of the product later. For instance, if under-ripe nuts are used, the cured product is said to be poor and shrunken while over-ripe nuts tend to be hard and light-colored. The sliced nuts are then boiled in a mixture of water and the previous year's extract called "Chogaru" for two to three hours in cauldrons. A common substitute for "Chogaru" is prepared by pounding barks of *Syzygium jambolanum* DC., *Pterocarpus santalinus* Linn., *Adenanthera pavonia* Linn. and *Ficus religiosa* Linn. with a few betel leaves and boiling them in water;

a little lime, jaggery, and gingili oil are added to give a shine to the nuts. The correct stage at which boiling is to be discontinued is determined when the embryo drops out and the slices assume a concave appearance. They are then removed and dried over mats. The decoction obtained after the charge is removed is boiled to the correct consistency to obtain "Chogaru"; this can be dried and preserved for use in subsequent years (50, 100, 153).

There are several variations in the method of processing and curing, viz., boiling in several changes of water, finished in boiling milk, boiling the whole nut with or without the husk intact in water and drying, or grinding the boiled kernels with spices and flattening them before boiling (50). These variations in the methods and in the state of maturity of the nuts collected for processing have induced the production of different grades of betel-nuts (61). Sometimes the nuts before export are boiled in water containing lime and dried (144).

In Malaya the tender nuts are processed in two different ways. "Pinang asin" is a preparation of tender nuts packed in gunny bags and mixed with salt. Storage for two to three months makes them ready for use. Sliced and dried tender nuts called "Pinang iris" are also prepared in Malaya for export (101).

When properly cured and dried, the nuts are dark brown with a glossy finish. Processed betel-nuts are always marketable as long as they are well cured and are of sound keeping qualities. The value of processing depends mainly on the selection of fruits of the correct stage of maturity and strict adherence to the intimate details of processing.

Chemistry of Arecanut

The arecanut, as already stated, consists of two distinct parts, the husk and the endosperm. In view of the distinctive nature of the parts comprising the fruit, details of their chemical composition are discussed separately, although it will be apparent that the husk is comparatively little investigated.

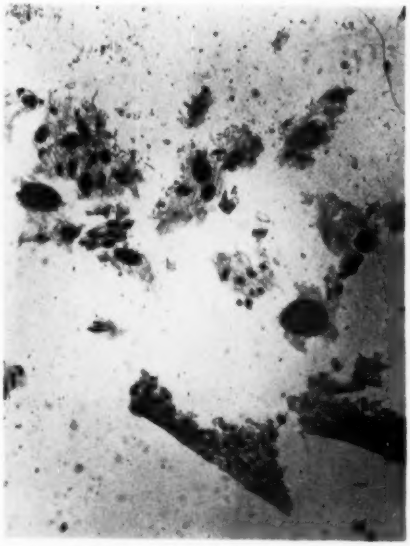

FIG. 10. A section of the husk showing separation of the individual fibers after maceration.

Husk. The husk consists of a large number of short staple fibers embedded in a matrix of thin parenchymatous tissue (Fig. 10). It varies in thickness from 1.0 to 1.5 cm. and can be divided anatomically into three zones: (1) the outer epidermal layer covered with the cuticle, (2) the middle layer which encloses the fibers, and (3) the hard and stony innermost layer appressed to the nut. The fibers adjoining the hard and innermost stony layer are large irregularly lignified groups of cells girdling the vascular bundles of the husk (hard fibers); the portion of the middle layer below the outer epidermal layer is composed of small groups of thick-walled cells, each group representing a fiber in cross section (soft fibers). No vascular

bundles are seen in this portion of the husk.

The first attempt to analyze the chemical composition of arecanut husk was made in investigations at the Imperial Institute, London (1922). These investigations produced the following data (134):

Analysis of Arecanut Husk

Moisture	10.1%
Ash	6.8%
Cellulose expressed on husks as received	42.6%
Cellulose expressed on moisture free husks	47.6%

According to Narayanamurti, Ranganathan, and George (106) and Harcharan Singh (66) the husk contains: moisture, 8.8; ether soluble, 0.933; alcohol-benzene soluble, 2.04; water soluble, 17.13; lignin, 27.04; cellulose, 64.80; pentosans, 23.43; and ash, 4.4 percent. Distillation with acid gave 18.75% of furfural.

Recently Baruah, Raghavan, and Murthy (15) have thrown further light on the chemical composition of arecanut husk at various stages of their development. A summary of their results is given in Table 2. From these investigations, it is immediately apparent that the principal constituents of the cell-wall materials of the husk are cellulose, lignin, and hemicellulose. The first two exist in combination as lignocellulose, but the nature of this combination is not determined. The husk is also reported to contain traces of tannins (8).

Erfan Ali and Khundkar (52, 53, 54) have analyzed chemically the lignin obtained from arecanut husk; nitration of the lignin gave three different fractions of nitrolignin of the minimal formula $C_7H_7O_5N$, $C_{13}H_{15}O_8N$, and $C_{17}H_{20}O_{10}N$. Oxidation of the lignin with nitric acid yielded 44% of oxalic acid.

Although it is difficult to make critical studies on the nature of the different cell-wall constituents of the husk with the data at hand, the results so far obtained have brought to light some phenomena which may be of far-reaching importance in any future studies on arecanut husk. It is now apparent that the cell-wall substances of the husk exhibit a series of changes associated with the degree of maturity, the cellulose and lignin attaining the maximum in the fully ripe husk. Generally, the mature husks contain less hemicelluloses than the immature ones. The epidermal and hypodermal cells of the husk also contain the green chloroplastid pigments which in the ripe husk are changed to carotin and xanthophyll giving the characteristic color to the fruit (15, 119).

The fibers of the husk are noted for their short staple length. The hard and soft fibers vary greatly in their physical appearance, the former being more ro-

TABLE 2

CHANGES IN THE PROPORTION OF THE HUSK CONSTITUENTS DURING MATURATION

Stages after 20-day intervals	Pectin %	Protopectin %	Hemicellulose %	Cellulose %	Lignin %
1	3.3	1.30	11.0	40.0	13.0
2	3.5	1.40	16.0	44.0	15.0
3	3.6	1.80	14.5	43.5	16.0
4	3.6	1.30	14.0	41.0	17.0
5	3.6	1.30	14.0	40.0	19.1
6	3.6	1.20	13.5	40.5	19.2
7	3.6	1.20	12.5	41.0	20.0
8	3.2	1.35	12.0	42.5	20.4
9	3.0	1.50	9.50	46.0	21.8

bust and brittle than the soft fibers (Figs. 11 & 12). The soft fibers are of a woolly nature with a smooth feel. A number of tests have been made to establish the chemical nature of the fibers, and it has been found that they answer all the reactions characteristic of lignocelluloses exactly in the same way as those of jute. A sample analysis gave the following: soft fibers—cellulose, 53.56%; lignin, 32.8%; hard fibers—cellulose, 71.32%; lignin, 26.6% (119).

Endosperm. The endosperm of arecanuts is a rich source of alkaloids, tannins, fats, carbohydrates, protein and non-protein nitrogen. The isolation of the alkaloids, which are reduced pyridine derivatives, can be credited largely to Jahns (75, 76, 77, 78), although it was Bombelon who made the preliminary attempts (67). In 1888 Jahns (75) reported the successful isolation of two alkaloids, a volatile liquid alkaloid, arecoline (methyl ester of arecaine—$C_8H_{13}O_2N$) which forms crystalline salts

FIG. 11. Surface view of the fibers.

FIG. 12. Surface view of woolenized fibers.

and arecaine or arecaidine (N-methyl derivative of guvacine). Two years later, he added a third alkaloid, arecolidine or choline (methyl ester of arecaidine). Three other alkaloids like guvacine (1 : 2 : 5 : 6-tetrahydropyridine-3-carboxylic acid), guvacoline (methyl ester of guvacine), and iso-guvacine isolated by different workers were added subsequently to the list of alkaloids of arecanuts (23, 67, 144).

From the number of available reports on the alkaloid content of arecanuts, it seems reasonable to assume that the quantity varies in fruits of different regions; it is even said that seeds from different palms show considerable variation in taste and alkaloid content. For instance, Kariyone and Fwa Tung (80) have given the alkaloid content of some varieties from Formosa and the South Pacific as ranging from 0.29 to 0.67%. According to Ferguson (58) and Claus (41) the nut yields 0.35% of ether soluble alkaloids calculated as arecoline. Quisumbing (117) has given the proportion of the different alkaloids as are-

caine, 0.1%, arecoline, 0.07 to 0.1% and others in traces. Chemnitius (35) has given the yield of arecoline hydrobromide in arecanuts as 0.35 to 0.40%. In a sample investigated in Assam, Raghavan (119) found only 0.15% of alkaloids, arecoline forming from 58 to 100% of it. Arecoline thus appears to be the major alkaloidal principle of arecanuts, generally varying from 0.1 to 0.5% (41, 144); it also appears to be the first formed alkaloid. Arecoline is a colorless, oily liquid (B.P. 230° C.) and forms crystalline salts with acids.

The tannins of arecanut also seem to have been subject to considerable investigation. During mastication of the nut, astringency, which is so well known a property, may be due to the tannin-alkaloid complex in the fruits, for the young fruits are in many ways different from the mature ones in taste. Ishikawa (73) was probably the first to draw attention to the tannin content of betel-nuts, the percentage of tannin in terms of tannic acid being 18.03 percent. A few years later Kay and Bastow (81) determined the tannin content of another sample and found it (in terms of oxalic acid) to be 14.88 percent. Subsequently, the fruit has attracted the attention of a number of workers as a promising possible source of tanning material (70, 62, 7, 71, etc.).

The characteristic reactions given by the arecanut tannins are as follows:

Reactions of Arecanut Tannins

Reagents	*Reactions*
1. Bromine water	Precipitate
2. Iron salts	Green color
3. Ferric alum	Greenish black precipitate
4. Lime water	Pink color
5. Dilute acids	Phlobaphene formed
6. Sulphuric acid	Crimson color

The arecanut tannins are predominently catechol tannins containing tannic acid, catechol (α-catechin), gallic acid, protocatechuic acid, pyrocatechine and phlobatannin; they also yield phlobaphenes and coloring matters when boiled with dilute acids (73, 38, 157, 37, 154, 41, 119). In their general properties the arecanut tannins closely resemble *Mimosa* bark tannins. Notwithstanding the fact that various reactions have been regarded as dependable because of their assumed conservatism and, therefore, used rather freely, the determination of the relationships of the different constituents that form the "tannins of arecanut" must ultimately be based on the preponderance of their similarities between pure and isolated samples, rather than upon the reactions given in groups of compounds. Before valid confirmation can be given to the above conclusions, a great deal more work should be done on what one may term the "dynamics" of the individual constituents of the tannins of arecanut.

The endosperm of arecanut is also reported to contain fats varying from 1.3 to 17.0% (149, 153, 113, 26). The fats agree in their general properties with those belonging to the butter fat or coconut oil group. The Reichert-Meissl values are low in comparison to that of other vegetable oils and fats and closely resemble that of coconut oil. Similarly, the saponification and iodine values approach the figures for butter fats. A characteristic feature of the arecanut fats is their low unsaponifiable residue which yields sterols (sitosterol) (125, 86, 91).

The chief components of the fatty acids are lauric (19.5%), myristic (46.2%), and palmitic (12.7%) and in the unsaturated portion oleic (6.2%), linoleic (5.4%), and hexadecenoic acid (7.2%). Minor proportions of stearic, decanoic, and of unsaturated monoethylenic C_{12} and C_{14} acids are also present. The chief component glycerides are (1) 56% of fully saturated (trimyristin, dimyristins and lauromyristopalmitin); (2) 30% mono-unsaturated-disaturated

(mainly hexadecenolauromyristin with some oleo-(linoleo)myristopalmitins and dimyristins); (3) 14% of diunsaturated-mono-saturated (oleolinoleoglycerides, mostly oleolinoleopalmitin). The fully saturated glyceride content of the fat is 53.7%. The fully saturated components are found to contain: 19.4% of lauric, 54.6% of myristic, 19.2% of palmitic, and 6.8% of stearic acids. The proportions of the various acids in the fully saturated components are similar to the corresponding ones in the saturated portion of the whole fat (113).

In addition to the alkaloids, tannins, and fats which have been comparatively more investigated, the endosperm is also stated to contain carbohydrates, protein and non-protein nitrogen, gums, saponins and vitamin A (116, 119, 99, 2). The proportions of the different constituents of the endosperm are tabulated in Table 3.

In an elaborate study of the derangements of the constituents of the endosperm, Raghavan (119) has produced a reliable picture of the changes taking place within that tissue from the time of its initial development to the time of full maturity; the data may be of considerable significance not only in elucidating the chemical composition of the endosperm, but also in explaining and interpreting certain biochemical reactions involved in its development. From this point of view the changes in the tannin content of the endosperm seem to be the most important. Perhaps no phenomenon is so obviously remarkable as the "disappearance" of the water soluble tannins during the final stages of ripening of arecanuts; a sudden decrease in the tannin content from 28% in the green fruit to 11% in the ripe fruit during the course of a few days is a remarkable chemical change invariably associated with maturity of arecanuts. This phenomenon is universal in many tanniferous fruits like banana, achras, persimmon, date, etc., and a number of hypotheses have been put forward from time to time to explain the specific transformation of the tannin during the final stages of maturity of the fruits. Study of the mechanism of the "tannin disappearance" in arecanuts has revealed that tannins of the unripe endosperm during the final stages of ripening are partly adsorbed by the cell-walls, partly transformed into granular carbohydrates, and in part used up in the formation of reserve celluloses (124).

It will be realized that certain constituents of the endosperm play a fundamental and unsuspected role in the events leading to the disappearance of the tannins. The total sugars of the en-

TABLE 3

CONSTITUENTS OF THE ENDOSPERM

Constituent	Quantity	Reference
Tannins	11.4–26.0%	62, 119
Gallotannic acid	18.03%	73
Gallic acid	...	154
D-catechol, $C_{15}H_{14}O_6$	3 gm./800 gm.	157
Phlobatannin	...	41
Alkaloids	0.15–0.67	119, 80
Arecoline	0.07–0.50	117, 41
Arecaidine, guvacine	Small quantity	67
Isoguvacine	Trace	67
Arecolidine, guvacoline	Minute quantity	67
Fats	1.3–17.0	149, 113, 26
Sitosterol	Trace	91, 86
Carbohydrates	47.2–84.5	116, 149
Saccharose, reducing sugars, galactan, mannan	...	154
Protein	4.9–9.3	116,149
Non-protein nitrogen	0.22–1.6	119
Saponins	...	37
Gums	...	99
Carotene (International vitamin A units/100 gm.)	5	116, 2
Mineral matter	1.0%	116
Calcium	0.0185–0.05%	149, 116
Phosphorus	0.13–2.352%	116, 149
Iron	1.5–11.6 mgm./100 gm.	116, 149

dosperm show an increase in amount with increasing maturity until the highest is reached in the fully ripe fruits. The non-reducing sugars which do not occur to any considerable extent in the young fruits show an increase at a rapid pace in the ripe fruits. The reducing sugars also register an increase in the ripe fruits. The mature fruits are also rich in protein and total nitrogen, total alkaloids, and fats in comparison with the young fruits. It is obvious that an elucidation of the relationship of the tannins and carbohydrates in the arecanut endosperm will indicate the modus operandi of the process of "disappearance" of the tannins and will have more than academic interest (**119**).

Utilization

Uses of Arecanut. Arecanut finds its chief use as a masticatory. Chewing of the betel-nuts is a popular habit enjoyed by nearly one-tenth of the human population. Such utilization of the fruit throughout the south and middle east Asia developed since it came into prominence centuries ago.

In recent times, however, there has been considerable effort in India to explore the indigenous raw materials for industrial uses to keep pace with the country's many-sided needs. The development of the tanning industry of the country has led to a great demand for those plants which are the natural storehouse of synthetic tannins. The importance of the kernels of green betel-nuts as a good tanning material has been stressed by many, and some (**8, 9, 137**) have indicated their possible utilization in tanning leather hide. Whereas these works were responsible for bringing the fruit to the forefront as a tanning material, they did not individually or collectively create an atmosphere of commercial utilization of this raw material. Further work is in progress at the Central Leather Research Institute, Madras, to bring the conclusions to a more satisfactory level, so that tanning of leather hide by arecanut tannins on an industrial scale may not be a long way off. The application of an extract of arecanuts for dyeing black and red shades has been in vogue in the Philippines for some time (**26**).

The betel-nut is also responsible for a number of medicinal uses. Of all the household remedies for tapeworm that filled the pages of some of the pharmacopocias and standard textbooks on pharmaceutical botany, perhaps no other has as successfully withstood the test of time until recently as arecanut. Appraisal of the therapeutic value of arecanuts varies to the extremes. At the height of its exploitation as a drug, various magic effects of therapeutic interest were ascribed to the nuts, which today seem to be preposterous and ridiculous. The introduction of synthetic drugs has considerably depressed the value of betel-nuts in the indigenous medical world, but the following discussion will focus the esteem in which the fruits were held not long ago.

In the Yunani system of India, the betel-nut is considered as digestive, astringent, and emmenagogue. It is recommended as a cardiac and nervine tonic and is used as an astringent lotion for the eyes. In Ayurveda the unripe fruits are considered as cooling, laxative, and carminative; dried nuts are said to sweeten the breath, strengthen the gums, remove bad taste, and produce a stimulant and exhilarant effect on the system, improving appetite and taste. The use of betel-nuts is recommended in calculous and urinary disorders and as an aphrodisiac in the form of a decoction with other aromatic and stimulant substances. The nut also finds its use as an external application to ulcers, for bleeding gums, and for urinary discharges in women. Burned and powdered, the nut is used as a dentifrice. It is useful for

checking heartburn in pregnancy, for blood in urine, and, boiled and compounded with red betel and spices, as a gentle stimulant. An extract of arecanuts significantly impaired phagocytosis *in vitro* in human beings, while no effect was noticed in guinea pig leucocytes (**32, 85, 51, 24, 25**).

From Cambodia have come some reports of the use of unripe nuts against diarrhea, dysentery, and as a laxative. In China a decoction of the boiled nuts is used as a medicine in visceral affections. Doses of the powdered nut have been reported to give satisfactory results in the relaxed condition of the bowels (**32**).

The reputation of arecanuts as an anthelmintic and vermifuge is quite well known. It is said to be effective against *Lumbricus, Taenia solium, T. saginata, Hymenolepis nana* and *Fasciolopsiasis buski* (**36, 4, 139, 72, 56, 57, 155**). Arecanut has also been used for similar purposes in veterinary practice in poultry and dogs; it is said to be used mixed with food as a preventive against diarrhea in horses (**23, 32**). In spite of its long use as a vermifuge, the action attributed to arecanuts on tapeworms, nematodes, and flukes is now considered doubtful (**46, 55**). Its use as an antidote to snake-poison, previously recommended (**95**), has been disproved (**33**).

The medicinal properties of arecanuts are ascribed to the presence of the alkaloid complex in the fruits. Arecoline is cholinergic and has action very similar to pilocarpine. Its central stimulant action is more powerful than that of pilocarpine, and with large doses paralysis may ensue. Arecoline increases the tonus and reflex movements of the muscles, chiefly those of the alimentary canal. It also causes constriction of the pupil and slowing down of the heart-beat rate, besides being a powerful sialogogue. Arecoline hydrobromide is recognized by some of the continental pharmacopoeias and is given hypodermically for catarrh in horses. It serves as a taenicide, anthelmintic, and diuretic (**32, 23, 67, 26, 27, 153**).

Vegetative parts of the palm have also been considered for a number of minor medicinal and other uses. In India the roots in decoction serve as a cure for sore lips, the buds as an abortifacient in early pregnancy in Malaya and as a cure for lumbago. The bark is useful for choleric affections and for flatulent, dropsical, and obstructive diseases of the digestive system; powdered young bark serves as an anthelmintic. An exudate from the tree is reported to form an inebriating lozenge. In Cambodia the roots form a remedy for liver disorders and jaundice and the leaves for cough and bronchitis. Half-rotted husks are used by the Chinese in Malayasia in dysentery. In the Philippines the buds of the palm (moisture, **91.48**; ash, **1.23**; CaO, **0.03**, iron as Fe_2O_3, **0.003%**) are eaten as salad (**32, 6, 117, 28, 27**).

An unfortunate phase in the development of the arecanut industry is that relating to the poisonous and other undesirable effects in human beings and livestock which at times become lethal. Chewing of the nuts in excess is said to give rise to temporary giddiness, griping, and strong intestinal irritations, followed by loose motions and may even lead to buccal carcinoma; mixed with opium the nut is administered in Malaya as a poison. In the indigenous medical system the unripe nut is described as pungent and saltish and causing biliousness and harm to the eyesight. Amateurs in betel chewing usually experience a disagreeable combination of symptoms including constriction of the oesophagus, sensation of heat in the head, red and congested face, and dizziness. The alkaloid arecoline is said to be highly toxic, its symptoms resembling those of fungus poisoning (muscarine) (**87, 32, 12, 85, 26, 96, 107**). A similar sensation is experienced while eating the buds.

Arecanuts are supposed to prevent the decay of teeth, but its continued use blackens them (153).

Uses of By-Products. The most important by-product of the betel-nut industry is the husk. It is estimated that in India at least 5,000 tons of husk may be available per annum. The possibility of utilizing the husk for industrial purposes has been an integral part of the previous investigations on this material. Although investigations carried out at the Imperial Institute, London, indicated the undesirability of utilizing this material for paper making, work undertaken later in India showed that boards of fine quality and insulating wool can be made of the husk. Boards, especially those prepared from the husk by the addition of certain sizing materials have shown high keeping qualities and finish (15). The husk can be used for the production of furfural (yield 13.45%), the residue left after furfural distillation being considered as a suitable filler for plastics (66, 105). Experiments on the production of activated carbon from the husk have also given encouraging results (1, 39, 40). The ash of the burned husk has been long used in Malaya as a dentifrice (28).

Manufacture of sundry articles from different parts of the palm has long been accomplished in the orient. Because of their hardness, the nuts are said to be used for making buttons. The stem has been used for inexpensive posts, rafters, trenails, beams, pillars, joints, scaffolding, water channel, spear handles, bows, walking sticks, and furniture. Leaf sheaths and spathes are now used in certain parts as a substitute for plantain leaves, for caps, and also for buckets, dishes, and wrappers. There is today an increasing use of the leaves in villages for thatching purposes. The central rib of the leaves is so strong that when dry and expanded it forms an excellent ready made splint. Inoculated with *Saccharomyces cerevisiae* the leaves can be used as a fermentation stimulant in industrial alcohol production. The traditional Indian practice has been to use the flowers of the arecanut palm on ceremonial occasions (51, 79, 100, 44, 26, 27, 150, 47, 65).

Conclusions

In India the arecanut has not been accorded as much attention as it deserves. This is presumably because of the localized nature of the crop and the unnoticeable impact of the commodity on the general economy of the country. It is gratifying to note, however, that the industry has made great strides during recent years, especially in improving the conditions of the growers and in initiating research on the still unexplored aspects of the palm. The eventual success of the industry in India will depend mainly on production, consumer demand, and the prices received for the product.

Future work on the improvement of arecanut should pursue the following broad objectives (20, 34, 100, 102, 112):

1. Obtaining higher yields through systematic cultural operations. On the basis of preliminary results, it now seems definitely possible that arecanuts can be produced at a higher rate through proper cultural and manurial methods. To the average holder this will mean that, with reasonable remuneration, production on a plantation scale should be a profitable undertaking.

2. Obtaining high-yielding, disease-resistant varieties through breeding. The segregation of the progeny due to unknown male parent seems to be apparent, and, therefore, inheritance of economic characters and self-behavior in controlled crosses are to be studied. It can be said that, ~~if~~ stability in arecanut growing on a plantation scale is to be reached, many new varieties will have to be developed and tested in order

to evolve varieties suited to particular areas and particular characters.

3. Describing and enumerating varieties of arecanuts in India and elsewhere to assist in a program of acclimatization and introduction of indigenous or exotic varieties under particular conditions.

4. Studying the biology of the commonly occurring diseases and pests and finding effective and economic measures to check them.

5. Making technological studies on the parts of the palm to evolve effective uses. Aside from those already listed, many new and stable industrial uses for the by-products of arecanuts should be found. This lack of spectacular phases has been one of the factors that has relegated arecanuts to the level of a mere "masticatory".

The impact of western civilization and the resultant ferment in Indian customs and habits seem to have drastically affected the arecanut industry. The future of the industry is not assured. Chewing of arecanuts is now being looked upon with disfavor. The many magic effects attributed to betel-nuts in therapy are still to be scientifically tested. Such endeavor is clearly of the greatest interest, in view of the urgent need to save the industry from what seems to be a crisis. If it is possible to develop arecanuts in the lines indicated at a rapid pace, the industry may survive.

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The Role of Natural Hybridization in the Derivation of Cultivated Tomatoes of Western South America

Although the garden tomato is very highly self-pollinated in most regions of cultivation, it is cross-pollinated at much higher rates in the range of its wild relatives—Ecuador, Peru, and northern Chile. Cohabitation of garden tomatoes and an intercompatible species in this region permits extensive gene exchange between them. These factors lead to a high level of variability and promote rapid evolution of new forms.

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Vavilov (**1949**) revealed the importance of studying variation in the region of origin to an understanding of the nature of cultivated plants. Having lived there for the longest periods, cultigens are likely to have acquired the greatest genetic variation in those regions. It is there also that they likely have had the greatest opportunity to hybridize with wild relatives. It is not surprising, therefore, that the richest source of agronomic and horticultural traits is to be found in accessions from their native region.

Races of cultivated tomatoes (*Lycopersicon esculentum* Mill.) from the main area of distribution of the genus—Ecuador, Peru, and Chile—have attracted remarkably little attention. In their survey of economic traits of a world collection of cultivated tomatoes, Hoover *et al.* (1955) have studied this neglected group to the greatest extent. The present report is not intended to satisfy the deficiency by providing a comprehensive analysis of its variations; instead, as an inquiry into several aspects of intra- and inter-specific hybridization, it is presented in the hope that it might shed a little light on the biological relationships of this fascinating group of cultivars.

Sufficient tests have been made to reveal that the cultivated tomato is almost exclusively self-pollinated throughout most of the regions of its cultivation (Rick, **1949**). Such intensive inbreeding renders it remarkably uniform; in fact, most modern horticultural varieties are effectively pure lines or populations of several very closely related pure lines. The situation in the native region in western South America is therefore of considerable interest. Evidence of much higher rates of natural cross-pollination there has been presented (Rick, **1950**), but additional tests are desirable, as are also studies of the impact of such out-

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crossing on the genetic composition of the native cultivated tomatoes.

Opportunity for conducting this study was afforded by two trips to the region in question and by subsequent periods of testing progenies of the original collections at Davis, California. Seeds were obtained from cultivated tomatoes collected in the field and in native markets. Field collections offer the advantages of affording observations on the plant characteristics and of comparing phenotypes in the same general environment. They also provide a better, though not certain, opportunity of gaining information about the source of seed, local history of cultivation, and other important aspects. All too often, however, such collecting is impossible, and the second choice of perusing native markets must be accepted. Despite the disadvantages of the latter, it still provides a remarkable means of assessing variations for the respective region. By keeping seed lots separate for each collected fruit, it is possible to progeny test single parent plants. From experience, furthermore, one learns how to distinguish fruits of different genotypes; i.e., from different source plants, so that a single visit to a native market place may often yield progenies from a large number of plants.

Vendors in the native markets can often supply satisfactory information about the source of their fruits. But usually little additional information can be gleaned, for all too frequently the produce has changed hands many times before it reaches the little heaps proffered by each señora in the mercado.

Whether fruits are collected in the field or in markets, the problem is inevitably encountered as to whether the races are native or recently introduced. The interval between my excursions was sufficient to permit detection of a considerable shift toward tomato varieties introduced from the United States. Trustworthy evidence of such importation can sometimes be obtained, but often it has to be deduced from comparisons of progenies grown in uniform environmental conditions. In many cases it is possible to distinguish criollo from imported varieties, but I would be rash to assume that I could distinguish all such accessions. In the material to be presented (see Table 2) all accessions were included to avoid bias.

Evidence of hybridization was gleaned from several different sources. In one situation it was possible to make an estimate of the actual frequency of natural cross-pollination. Observations of plants growing in the field often afforded critical information. Finally, the most valuable source of data is the series of observations made on progenies of collections as grown in a relatively uniform garden at Davis, California. These can often reveal the degree of heterozygosity or even the proportion of outcrossing of the parent plant and thereby supply a surprising amount of genetic information.

Since such studies constituted only one of several objectives of the expeditions, the information is necessarily scattered and often disappointingly brief for certain areas. Scraps of information and seed samples must be gathered here and there as exigencies of travel permit. Opportunity was seldom encountered for a very intensive survey of any single region. Despite the brevity of the data, all of it points in the direction of unusually high frequencies of cross-pollination.

Direct Measurement of the Rate of Natural Cross-Pollination

Hybridization was likely responsible for most of the variations described in this article, but none of the other tests affords satisfactory data for estimating the frequency of hybridization. The rates of natural crossing measured by Rick (1950) by the use of male-sterile mutants in the same region were many

times higher than rates recorded for the United States.

A new opportunity for making such a test was provided when I visited the Chile-Peru frontier region in February, 1957. The experiment was not planned but was made to order by the presence of about 5% of plants with the potato leaf phenotype in most of the fields that I visited. Since this easily recognized leaf variation is determined by a single recessive gene, *c*, potato leaf plants must be homozygous (*c*/*c*). It follows that any normal-leaved progeny from such plants must issue from hybridization with nearby normal plants and that their frequency should permit a simple but effective means of estimating the rate of natural cross-pollination. The test could therefore be made by harvesting fruits singly from each of a number of *c* plants scattered throughout the planting, extracting and sowing the seeds, and counting the numbers of potato and normal leaf plants. The difference between the two leaf types can be detected in the early seedling stage.

The low but consistent appearance of *c* plants *per se* suggests hybridity. It is also possible that *c* contributes some horticultural advantage to the plants in either homozygous or heterozygous condition, or both. I doubt that the growers, who make a practice of saving their own seed from year to year, intentionally select in favor of *c*, because none of the five growers I met was even aware of the difference in leaf shape until I called their attention to it. The plants in all observed fields had been fruiting for several months and were closely planted in rows, staked and intimately intermingled, thereby providing a good opportunity for cross-pollination.

Collections were made in three representative fields in which typical tomatoes were being grown. Growth was so poor and the number of plants so small for a planting in the Lluta Valley in northernmost Chile, however, that the sample was insufficient for a satisfactory estimate. The other two collections were made in the Tacna Valley in southern Peru—one in the outskirts of the city of Tacna and the other at Calana, 13 km. to the east. Growth in both fields was excellent. The fields were veritably alive with various small species of solitary bees of the family *Halictidae*, which were busily gathering pollen from the tomato flowers. Not having the necessary equipment, I was not able to collect any of these insects. The data from these tests are summarized in Table 1.

Knowing that approximately 5% of the plants in both fields were *c*/*c*, the overall frequency of the gene *c* can be estimated at 22.4%. Since the products of $c \times c$ cross-fertilizations would go undetected, the proportion of normal seedlings must be adjusted by the factor 1/0.776. The estimates of natural cross-pollination thereby obtained are given in the last column of Table 1.

The rates estimated for the two fields —25.7 and 14.8%—are in keeping with the high rates estimated previously

TABLE 1

PERCENTAGE NATURAL CROSS-POLLINATION IN TWO LOCALITIES IN SOUTHERN PERU

Source	No. of fruits	Seedlings			%+	Adjusted % NCP
		+	*c*	Total		
Calana	15	420	1692	2112	19.9	25.7
Tacna	10	202	1555	1757	11.5	14.8
Total	25	622	3247	3869	16.1	20.8

(Rick, 1950) for other areas in coastal Peru and are vastly greater than those reported for other areas of tomato cultivation. An exception to the latter statement is given in the work of Richardson and Alvarez (1957) in their comprehensive tests of Mexican tomatoes, utilizing the same genotypes and technique. Their estimates ranged from 0.3–1.9% at Chapingo to 8–11% at Jaloxtoc and seemed to be related to the observed activity of native bees visiting tomato flowers. It is probably of considerable significance that these exceptionally high rates for tomatoes were registered for tropical or subtropical regions, where the activity of native bees is usually at a high level.

Genetic Variability in Single Fruit Progenies

Small families of plants were grown, each derived from separate fruits collected in various tomato-growing regions of Ecuador and Peru. Fruit lots of the original collections were selected to represent as nearly as possible the range in variation of fruit types that were encountered. The number of plants per progeny—usually 10—was entirely inadequate for a complete sampling of variability. In order to detect the segregation of a monogenic recessive character, for instance, samples of this small size would fail on the average in 6% of the progenies. The adopted sample size would therefore tend to underestimate genetic variability. In spite of this shortcoming, the data reveal a remarkable increase in variability over lines known to be genetically uniform.

Plants of these progenies were grown in the field at wide spacing and were observed throughout the growing season. With them were planted samples of seven U. S. tomato varieties known to be genetically homozygous. All families were routinely scored for a group of morphological characters, two of which are qualitative and permit classification into two classes, and two quantitative, requiring classification into multiple classes. Of the former, axes of inflorescences were classified simply as to whether they were branched or simple, disregarding the degree of branching within the branched group. It is not implied by this classification that inheritance is monogenic. The other qualitative character, fasciation of fruit, has a well-known monogenic determination, the recessive gene *f* conditioning a foreshortened, multilocular, and often deformed fruit, in contrast to the much less distorted and more oblate fruit of the dominant allele, f^{+}. The quantitative traits measured were mean number of locules per fruit and length of exsertion of stigma beyond the tip of the anther tube. Number of locules is correlated to some extent with segregation for *f*, but considerable additional genetic control of a polygenic nature exists. Less is known about determination of stigma position except that it likely also has a quantitative genetic determination. A considerable environmental control is known (Howlett, 1939). In the present test, efforts were maintained to reduce environmental variance as much as feasible by growing the progenies in a compact plot and by reading stigma positions of all progenies within the shortest possible time. The differences between the South American accessions in mean stigma position and in variability of its position strongly indicate that at least part of the control of exsertion is genetic. Additional monogenic characters were recorded whenever they were encountered. Incidental variation was thus found for the following genes: *H* (absence of large trichomes), *r* (yellow fruit flesh), *y* (colorless fruit skin), and *wt* (wilty or adaxially curled leaves). More details concerning the action of these genes are given by Rick and Butler (1956).

TABLE 2

VARIATION IN INHERITED CHARACTERS OF CULTIVATED TOMATOES FROM ECUADOR, PERU, AND CHILE

Number of collection*	Locality of collection	Inflorescence		Exsertion of stigma mm.					Number of fruit locules									Fruit fasciation		Other segregation**	Remarks
		Branched	Unbranched	0	1	2	3	4	2–3	4–5	6–7	8–9	10–11	12–13	14–15	16–17	18–19	+	f**		
126-1	Quito, Ecuador	8	2	3	3	3	1				1	1	1	4	3				10	2+: 8y	Highly variable plant size and habit, leaf shape
126-2		10			2	7	1					5	4	1					10		Rather uniform line
127-1	Ambato, Ecuador	2	8		8	2													10		Rather uniform line
117-1	Piura, Peru	10		9	1							2	6	2							Rather uniform line; all = y
117-2		9	1	6	1	2			2	6	1	1						8	2	4H/+: 6H	Segregation for yellowish vs. green leaf color
117-3		10		10									1	3	1	2	3		10		Uniform, all = H and foliage odor of *L. pimpinellifolium*
117-4		9		9								1	3	3	1				9		Uniform, all = y and *wt*
117-5		8			8						1	4	2		1				8	6+: 2r	Uniform in vegetative characteristics
117-6		1	7	1	1	5		1	2	5	1							7	1	1+: 5H/+: 2H	Very variable in many vegetative characters
117-7		9		8	1							5	4						9	8H/+: 1H	Variable; resembles *L. pimpinellifolium* in habit and leaf shape

TABLE 2 (*Continued*)

Number of collection*	Locality of collection	Inflorescence		Exsertion of stigma mm.					Number of fruit locules									Fruit fasciation		Other segregation**	Remarks
		Branched	Unbranched	0	1	2	3	4	2–3	4–5	6–7	8–9	10–11	12–13	14–15	16–17	18–19	+	f**		
115-1	Chiclayo, Peru	10		6	3	1						1	7	2					10		Rather uniform, many characters suggest *L. pimpinellifolium*, all = *H*
115-2		10		6	2	2						1	7	2					10	4*H*/+ : 6*H*	Very similar to 115-1
113-1	Chepen, Peru	4	6	1	7	2			5	4	1							10			Highly variable in many characters, sug. *L. pimpinellifolium*
125-1	Trujillo, Peru		10	2	5	2	1				3	7							10		Variable habit and leaf shape
125-2		10			2	5	3				2	6	1						10	4+ : 6*y*	Very uniform; resembles *L. pimpinellifolium* in foliage odor, etc.
125-3		10			1	8	1				1	4	2	2		1			10	2+ : 8*y*	Fairly uniform
125-4			10	6	3	1						8	2						10		Very uniform; resembles U.S. var. Stone
125-5			10	3	2	5					5	4	1						10		Similar to 125-4
134-1	Ayacucho, Peru	1	9	9			1		9					1				9	1	9+ : 1*H*	Variable in many characters
134-2a		6	4		8	2				6	2	2						6	4		Variable in leaf and fruit shape
134-2b			10	3	7				7	3								10		9+ : 1*wt* 8+ : 2*y*	Variable leaf shape, otherwise fairly uniform

TABLE 2 (*Continued*)

Number of collection*	Locality of collection	Inflorescence		Exsertion of stigma mm.					Number of fruit locules									Fruit fasciation		Other segregation**	Remarks
		Branched	Unbranched	0	1	2	3	4	2–3	4–5	6–7	8–9	10–11	12–13	14–15	16–17	18–19	+	f**		
134-3		10				8	2				1	9							10	6+: 4y	Variable in habit, leaf color, otherwise fairly uniform
134-4		10			2	8				1	4	4	1					1	9	2+: 7y	Rather uniform
131-1	Arequipa, Peru	1	9	10					10									10			Appears identical with var. San Marzano
131-2			10	10					10									10			Appears identical with var. San Marzano
131-4		9				6	3				8	1							10		Very uniform line with unusual fasciated pyreform fruits
131-5		9		1	2	5	1				1	4	2	2					9		Very uniform
131-7		9	1		5	5				1	1	3	4	1				1	9		Marked variation in habit, leaf shape and fruit size
131-8			10	10					9	1								10			Very uniform; resembles var. Red Pear
131-9a		7	3	2	2	4	1					2	5	1	2						Habit variable; otherwise uniform line; all = *wt*
131-9b		9			1	4	4				1		1	1	2	3	1	1	8	1H/+: 8H	Uniform except for habit; all plants *wt*

TABLE 2 (*Continued*)

Number of collection*	Locality of collection	Inflorescence		Exsertion of stigma mm.					Number of fruit locules									Fruit fasciation		Other segregation**	Remarks
		Branched	Un-branched	0	1	2	3	4	2–3	4–5	6–7	8–9	10–11	12–13	14–15	16–17	18–19	+	f**		
131-10	*	10			4	5	1					6	3	1					10	4+: 6y	Moderately variable; all = strongly *wt*
303	Moquegua, Peru	4	1	1	2	2				2	3							5		3+: 2c 1+: 1*H*/+: 3*H*	Total seedling segregation was 7+: 4*c*
299	Arica, Chile	1	4		2	3			1	2	2							3	2		Variation in many characters; all = *wt*
Gulf State Market	U.S.		10	10						1	8	1						10			Very uniform; all = *y*
Golden Queen	U.S.		10	9	1					1	6	2	1					10			Very uniform; all = *r*, *y*
Pritchard	U.S.		10	10							9	1						10			Very uniform; all = *sp*
Early Santa Clara	U.S.	10		9	1									3	4	2	1		10		Very uniform
Rutgers	U.S.		9	9						1	8							9			Very uniform
Pearson	U.S.		10	10							8	2									Very uniform; all = *sp*
San Marzano	U.S.	1	9	10					10									10			Very uniform

*Each entry is the progeny of a single collected fruit.

**Key to gene symbols (more extensive descriptions given by Rick and Butler, 1956):

f—Fruits fasciated, having an increased number of locules with consequent changes in form.

H—Vegetative parts lack large multicellular trichomes of the normal (+) tomato. The heterozygote, *H*/+, has an intermediate number of hairs.

r—Fruit flesh yellow instead of the normal (+) red color.

sp—Self-pruning or determinate habit.

y—Skin of fruit colorless instead of the normal (+) yellow color.

wt—Leaf margins rolled, imparting a wilted appearance.

The measurements are summarized in Table 2, wherein the families are listed in order of site of collection, proceeding from north to south. Since most of the fruits were collected in native markets, the reader should be warned that the site of collection may not necessarily have been the same as the site of cultivation. Collections made in Quito, for example, almost certainly did not originate there because the climate of Quito and its environs is not favorable for tomato cultivation; they likely had been transported from lower areas, even from great distances. It is known, likewise, that most of the tomatoes sold in Arequipa are produced in lower, warmer areas, such as the Vitor Valley. Although brief, this survey is adequate to reveal an amount of progeny variability that is astonishing for cultivated tomatoes. No less than **18** of the **34** Latin American collections show segregation for Mendelian traits and include a total of **25** separate segregations. The remaining families are generally much less variable in quantitative traits. It is entirely possible that the latter group might include recently imported tomato varieties from north temperate countries. The contrasted high level of uniformity and characteristic phenotype, for instance, strongly suggest that progeny no. **125-4** might be the U. S. variety Stone, and a marked resemblance exists between **131-1** and **131-2** and var. San Marzano, and between **131-8** and Red Pear. If these are eliminated from consideration, only 5 progenies of a total of **30** are as uniform as the U. S. varieties treated here as controls. Such a high level of variation in cultivated tomatoes is a completely new experience for anyone used to working with U. S. varieties, which are highly inbred generation after generation, thanks to the natural mechanism for self-pollination of the tomato flower and lack of insect pollen vectors in the U. S.

Impressions of great variability in the sharply segregating characters are strengthened by observations of shape, texture, and color of leaves and many other less easily measured characters. After repeated experience with pure-line tomato progenies, the observer soon becomes sensitive to such hereditary variations of less tangible nature. The last column in Table 2 is reserved for brief summaries of observations on such characters. These generally tend to confirm the aforementioned indications of unusually high genetic variability.

Table **2** presents information concerning variation in number of fruit locules but does not adequately reveal associated changes in size or shape of the respective fruits. Photographs of fruits of a few lines (Figs. 1–3) are therefore included to show the extreme variation in fruit characteristics of three progenies from northern Peru. They are accompanied by a similar illustration (Fig. 4) of the sample of variety Pearson from which the data in Table **2** were taken. Several representative fruits were taken from each plant of the respective progenies and are shown in the figures in proximal, lateral, and transverse sectional views. The increase in variability in the various fruit traits of **113-1**, **117-2**, and **117-5** as compared with Pearson is so marked that it does not require further comment here.

Of the several possible sources of genetic variability, hybridization is most likely responsible for the phenotypic variation summarized in Table **2**. Hybridization in the preceding generation can be proved for some of these progenies. Thus, fruits from which progenies **126-1** and **134-4** were derived had a fasciated phenotype and therefore must have been harvested from homozygous *f/f* plants; likewise, **125-3** and **131-10** were derived from fruits with colorless skin, necessarily produced by *y/y* plants. But, since plants with normal (+) pheno-

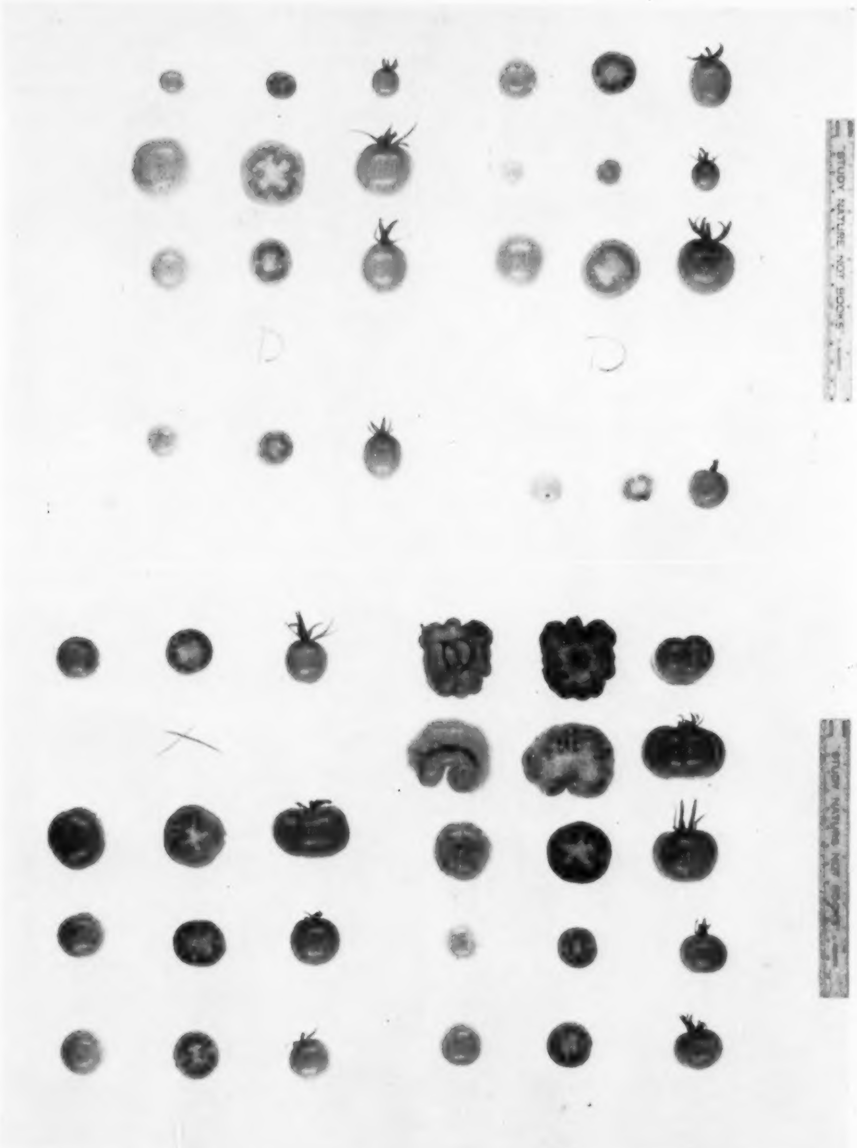

Fig. 1 (Upper), Fig. 2 (Lower). Fruit samples from individual plants, each group of three taken from a different plant. In each group the distal (left) and transverse sectional (center) views are of the same fruit, the lateral view (right) being taken of an additional fruit. The symbols D and X indicate plants that were lost before the time photographs were taken. Fig. 1. Progeny of single fruit from Chepen, Peru (113–1). Fig. 2. Progeny of single fruit from Piura, Peru (117–2).

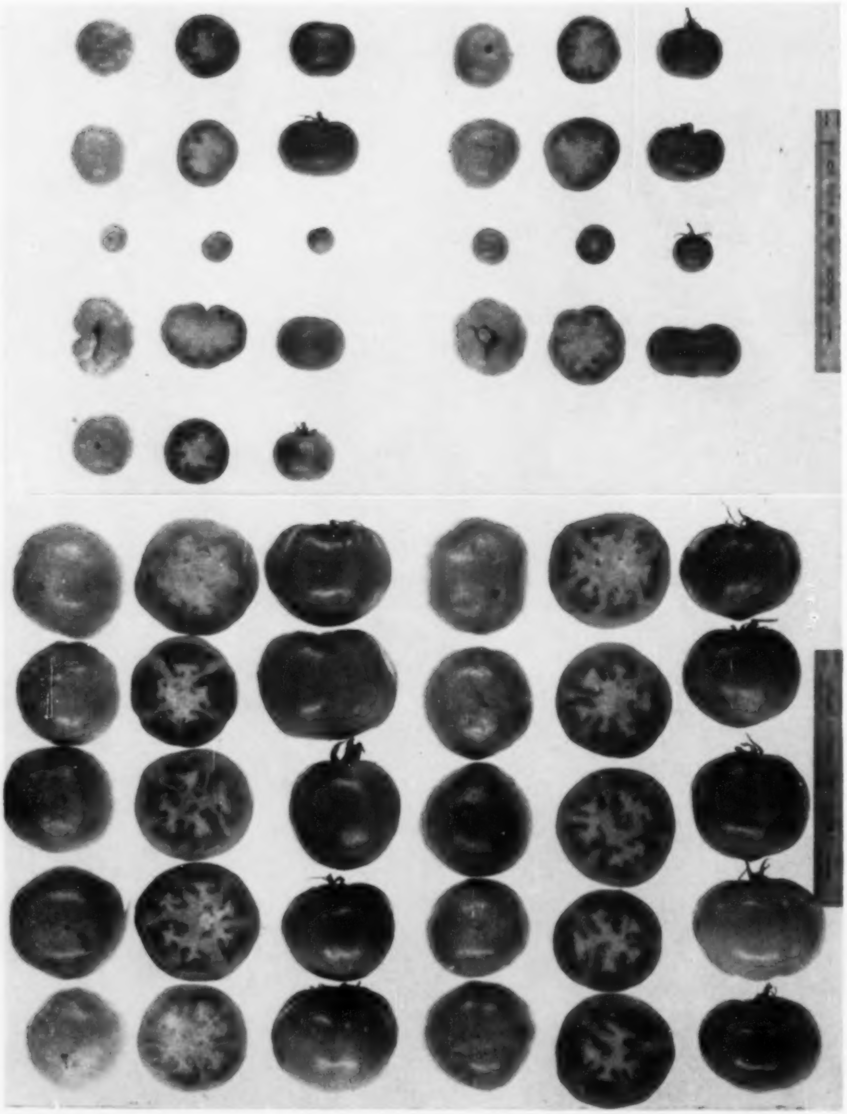

Fig. 3 (Upper), Fig. 4 (Lower). Progeny fruit samples. Fig. 3. Progeny of single fruit from Piura, Peru (117–5). Fig. 4. var. Pearson. See legend of Figs. 1 and 2 for explanation.

type appeared in their progenies, they must have resulted from outcrossing with other plants that were either homozygous or heterozygous for the respective normal allele. It is unlikely that all the observed genetic variability arose from immediate hybridization; it would be more reasonable to assume that it resulted from segregation in plants whose heterozygous condition was derived from hybridizations in preceding generations.

Traits of *Lycopersicon pimpinellifolium* Appearing in Cultivated Tomatoes

Evidence has been given in the foregoing sections of natural hybridization among cultivated tomatoes of western South America. Throughout the Ecuadorian littoral and northwestern and west central Peru, the wild currant tomato, *L. pimpinellifolium* (Jusl.) Mill., occurs abundantly as a weed in cultivated fields. It has been demonstrated many times by many workers that this species is completely cross-compatible with the garden tomato, and that the hybrids of such crosses and their progeny are likewise completely fertile. It is not surprising, therefore, that the two would hybridize spontaneously and that, consequently, traits of the wild parent would eventually turn up in native forms of the cultivated tomato. For this introgression there is a plethora of evidence.

Some indications of the flow of genes from *L. pimpinellifolium* to *L. esculentum* is contained in data already presented. For example, eight of the 34 progenies listed in Table 2 either segregate or are completely fixed for the hair-modifying gene, *H*, which is characteristic of the currant tomato and is practically unknown in tomatoes from other regions of the world. When homozygous, this incompletely dominant gene eliminates the large trichomes, leaving only the smaller simple and glandular hairs. In the region sampled, this trait appears far more frequently within the range of *L. pimpinellifolium*, although it is listed for a few collections in southern Peru (131-9b and 303), and I have also observed it in other collections from northern Chile, where apparently *L. pimpinellifolium* does not occur. This trait reaches a crescendo in coastal Ecuador, where apparently all native cultivated tomatoes carry it in homozygous condition. I saw tomatoes cultivated in six different parts of this region and without exception every plant had the *H/H* genotype. Likewise, the same genotype was found in every plant of the progenies of 36 different plants from various parts of this region. By contrast, collections from the Ecuadorian sierra (Table 2) and oriente (eastern slopes of the Andes and Amazonian lowlands)—both presumably outside the range of *L. pimpinellifolium*—uniformly exhibit the typically hirsute condition of *L. esculentum*. It is particularly significant that this trait appears at greatest concentrations in the sympatric region and is scarce or absent outside the range of the wild species.

The same relationships are exhibited by another gene, curly mottled (*cm*), which is most remarkable for its distribution and expression. It was discovered by C. F. Andrus at the U. S. Regional Vegetable Breeding Laboratory, Charleston, South Carolina, in an accession, PI 196,297 from El Recreo, Nicaragua, and its inheritance was later studied by Rick and Butler (1956). When this gene is homozygous and environmental conditions are favorable for its expression, leaves are severely distorted as if afflicted by a virus disease (Fig. 5). Associated with the greatly reduced leaf blade area is a peculiar, irregular, fine striation of whitish color. In maximum expression flowers are drastically reduced and infertile. The tests to demonstrate the critical range of environmental conditions for *cm* expression have yet to be made, but stocks have

FIG. 5 (Upper), FIG. 6 (Lower). Effects of *cm* on leaf form. FIG. 5. Representative leaves showing moderate symptoms. FIG. 6. Branch of *cm/cm* plant photographed in July, 1957, showing progressive change from strong *cm* effects on the older leaves (right) to nearly normal structure in the younger leaves (left).

been grown here under enough different regimes of temperature to demonstrate that it tends to become more extreme at night temperatures below 62° F. and often fails to gain expression at those above 65° F. Interactions of night temperature with day temperature, light intensity, and other factors might also be important. Sudden shifts to low temperature seem to accentuate *cm* expression. Thus, the most extreme symptoms are commonly seen in California shortly after transplanting to the field. Thereafter, they gradually diminish until midsummer, when leaves may become entirely normal, but gradually reappear in the fall, never regaining the intensity observed in the spring. Fig. 6 illustrates the transition from strong to mild expression in the leaves of a branch of a *cm* plant growing in the field in the early season. When conditions are most favorable for the expression of *cm*, it can produce mild effects in heterozygotes. These details of the expression of *cm* are mentioned here because they have an interesting bearing on its appearance in tropical tomatoes.

Up to the present time progenies from 34 different cultivated tomato plants from various stations in coastal Ecuador have been grown under conditions favorable for the expression of *cm*. Twenty-nine progenies were homozygous for *cm*; three segregated; and the *cm* phenotype did not appear in two. Intensity of expression varied considerably between families. It is also characteristic of a line (LA292) previously described (Rick, 1956) from the Galápagos Islands. In addition, the same phenotype appears in collections of *L. pimpinellifolium* from Pichilingue, Ecuador, but has not been detected in others from Daule, Puná, and Cerecita—stations of the Ecuadorian littoral. Test crosses were made between the original source of *cm* and representative collections of the new forms (*L. pimpinellifolium* from Pichilingue, *L. esculentum* from Guayaquil, and LA292 from the Galápagos) showing similar phenotype. The appearance of the *cm* phenotype in all the progeny of each cross proves that the same gene or a very similar one is carried at the same locus by these Ecuadorian tomatoes. The possibility of a different allele must be admitted especially because the phenotypic expression of the Ecuadorian material differs from that of the original Nicaraguan line in having less striation.

These tests detected the presence of *cm* or a similar allele in the Galápagean accession LA292 and in most of the tested cultivated tomatoes from the Ecuadorian coast. It has also been established that *cm* is absent in all other accessions of *Lycoperiscon* from the Galápagos Islands. Other similarities between LA292 and tomatoes of coastal Ecuador and differences between LA292 and the bulk of Galápagos tomatoes are to be found in color and size of fruit, foliage odor, growth habit, and other traits. In the light of this evidence, it is likely that LA292 was introduced by colonists to the islands, where it escaped from cultivation.

The widespread distribution of *cm* in coastal Ecuador is particularly intriguing. While travelling there I could detect none of its manifestations in growing tomato plants; in fact, I was totally unaware of its presence in any of the lines. Not until progenies were grown in California did *cm* become evident in the progenies. It appears very likely that the phenotypic expression by which we identify *cm* is masked by high temperatures and possibly other environmental conditions prevailing throughout the year in the native habitat. If this is granted, the problem then arises as to why this gene has become fixed in so many wild and cultivated forms and in regions so distant as Ecuador and Nicaragua. It seems very likely that it offers some selective advantage under

tropical conditions, but what this advantage might be could scarcely be guessed when its morphological expression is completely masked by the environment.

Whatever the solution to this mystery, the presence of *cm* in most observed cultivated tomatoes of coastal Ecuador and in some accessions of *L. pimpinellifolium* from the same region and its absence in all other accessions of cultivated or wild tomatoes, except the original source from Nicaragua, point to a common source for this gene. As in the foregoing instance of *H*, *cm* likely originated in *L. pimpinellifolium* and was transferred to cultivated tomatoes by introgression. The possibility of the reverse gene flow from cultivated to wild forms cannot be ruled out with available information. Whichever the direction, however, the presence of *cm* in both species argues for hybridization and subsequent introgression.

Associated with *cm* in cultivated tomatoes of the Ecuadorian littoral is another unique character—absence or great reduction of foliage odor. Again, all accessions that I have tested from this region are characterized by this odorlessness. The same condition was reported for the presumed escaped cultivar, LA-292 of the Galápagos Islands (Rick, 1956). In all of these lines the depression of foliage odor is accompanied by a reduction in the size of glandular hairs, and it appears likely that the former is a consequence of the latter. Although definitive inheritance studies have not yet been made, it appears from preliminary tests that odorlessness is dominant and simply inherited.

A relationship between the cultivated and wild tomatoes of coastal Ecuador cannot yet be established for odorlessness since all wild accessions observed to date are strongly endowed with typical *pimpinellifolium* foliage odor. Even though a wild source of this trait has not yet been established, it is still possible that the character in question originated from hybridization between the two species. The loss of odor could have originated from hybridization if odor were determined by genes at different loci in the two species. The marked difference in quality of pungency between the two indicates a different genetic determination although not necessarily at different loci. In experiments with another species hybrid—that of *L. esculentum* × *L. peruvianum* (L.) Mill., which differ markedly in odor—I have found a small proportion of segregants that entirely lack odor. It is therefore conceivable that odorlessness in these cultivated forms might have been derived from hybridization with *L. pimpinellifolium*.

A consideration of tomato foliage pungency in collections from northern Peru—another highly critical area—provides more concrete evidence of introgression. Among collections listed in Table 2, none is odorless or segregates for that character, but several of the accessions from Piura and Chiclayo (115-1 and 117-3) have the unmistakable odor of *L. pimpinellifolium*.

The evidence of introgression of odor from *L. pimpinellifolium* is greatly reinforced by observations of many other vegetative characters in the same accessions. The following *pimpinellifolium* traits, which do not appear in other cultivated tomatoes, either segregate or are characteristic of every plant in accessions from northern Peru: smaller, less dissected leaves; broader leaf segments; lighter, yellow-green foliage color; and a greater tendency of the plant to branch. The net effect of variation in all of these characters is a striking change in the entire appearance of the plant in the direction of the wild species, which is obvious to the observer even at a considerable distance.

Finally, variations in fruit size and shape provide additional evidence of the presence of *pimpinellifolium* germ plasm

in these cultivated tomatoes. This variation was presented in detail in a preceding section as testimony of hybridity, but, in the light of other characters, it is difficult to avoid the conclusion that hybridization between large-fruited cultivars and *L. pimpinellifolium* was responsible for this remarkable range of variation. The pattern of variation presented in Figs. 1 and 2, for example, is almost as large as that observed in the F_2 of a cross between the two species. It is not unreasonable that the parent plants might have actually been F_1 hybrids. Another example, pertinent to this situation, is a series of plants that I encountered in a cultivated field on the large island of Puná in the Golfo de Guayaquil, Ecuador. In this single field there was virtually a complete range of variation in fruit size—including fasciated and non-fasciated forms—from the typical large criollo tomatoes of the region to others almost as small as the native *L. pimpinellifolium*. A representative sample of fruits from this field is the subject of Fig. 7. In this example again, the implication of *L. pimpinellifolium* is overwhelming. Such an enormous range of variability in fruits cer-

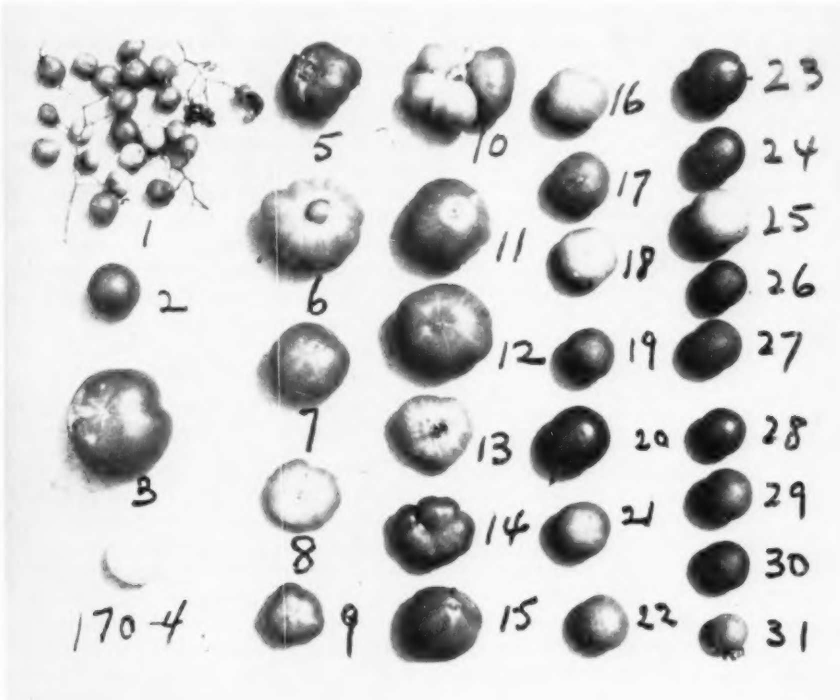

FIG. 7. Representative fruits of LA417 (SAL 170) from a cultivated field on the Island of Puná, Ecuador. Each fruit or group of fruits was harvested from a different plant. The largest fruit (No. 3) was approximately 7 cm. in diameter. From a 35-mm. kodachrome taken in the field.

tainly cannot be desired by the growers, who are well aware of the market demands for large-sized fruits, if not of shape and surface configuration to please U. S. tastes. This section can be concluded by stating that hybridization between the two species offers the simplest and most reasonable explanation for the variations of local *esculentum* varieties in fruit size and locule number and in many attributes of leaves, including the monogenic characters *H* and *cm*.

Variations in *L. pimpinellifolium*

The appearance of so many traits of *L. pimpinellifolium* in cultivated tomatoes of Ecuador and northern Peru naturally raises the question as to the reciprocal relationship: is there evidence of introgression of *esculentum* traits into *L. pimpinellifolium?* No attempt was made systematically to grow and study in detail all available accessions of the latter species. The few observations reported here were gleaned incidentally to other studies and are therefore not pretended to be an extensive survey of morphological variation in that species.

As seen in their native habitat and in our cultures of single-plant progenies, most accessions of *L. pimpinellifolium* show remarkably little variation and conform to descriptions of the species. All forms that have been tested are self-compatible, and the majority of progeny doubtless result from automatic self-pollination. Nevertheless, some collections have been found to show exceptional traits and in some instances segregate for them. Particularly noteworthy is a collection (LA114) found in an abandoned field near Pacasmayo, a seaport on the north coast of Peru. In some of the pedigree progenies from this collection, segregation was observed for H^{+}, the presence of large epidermal trichomes, and *y*, the colorless skin condition. Neither of these traits is characteristic of *L. pimpinellifolium*, yet both are common in *esculentum* varieties of this general region. An unusual amount of variation was also observed for size and shape of leaf and other vegetative characters. Pubescence of the *esculentum* type has also been seen in collections of *L. pimpinellifolium* taken near Chiclayo, Peru; furthermore, segregation for the same character and also for fruit size was seen in LA376, a collection made at Hacienda Chiclín in the Chicama valley north of Trujillo, Peru.

In spite of my rather limited experience with the currant tomato, it has been sufficient to reveal extensive variation between populations and segregation within populations for traits that are otherwise associated with *L. esculentum*. Again, introgression offers the most logical explanation for this association of morphological characters.

DISCUSSION

Relationships Between *L. esculentum* and *L. pimpinellifolium*

Evidence has been presented of frequent hybridization in the reproduction of cultivated tomatoes of western South America. *L. pimpinellifolium* occurs abundantly as a weed in cultivated fields of the northern part of the range studied. The experiments of several workers (reviewed by Rick and Butler, 1956) reveal no barrier to gene exchange between these two entities. Ample opportunity therefore exists for hybridization between the two. The presence of *pimpinellifolium* genes has been demonstrated in *L. esculentum* and *vice versa*. Introgression offers the likeliest explanation of this pattern of gene distribution.

This introgression and consequent blending of characters of *L. esculentum* and *L. pimpinellifolium* raises the question of the taxonomic status of these two entities. As mentioned before no barrier of any consequence exists to prevent gene exchange between them. Not only

do the chromosomes of the 2N F_1 hybrid pair without any irregularity, but also, when they can "choose" between pairing with homologues of the same parent or with those of the other parent, as in 4N hybrids, pairing occurs at random (Lindstrom and Humphrey, 1933).

Turning to morphological comparisons, it must be recognized that the difference in form between the two entities becomes unnecessarily extreme if one adopts the natural but misleading assumption that familiar horticultural varieties should be taken as the species concept of *L. esculentum*. Fruits of such varieties are literally hundreds of times larger, and other organs are likewise larger than those of *L. pimpinellifolium*, although in smaller proportion. The only valid comparison that can be drawn is with the wild form of *L. esculentum*, var. *cerasiforme*. The contrast in size of organs with the latter is very much less, its fruits being roughly half again or twice as large in diameter or three to eight times as large in volume as those of *L. pimpinellifolium*. This divergence in fruit size and a difference in shape of corolla lobes constitute the key characters for separating the species (Muller, 1940).

If it can be demonstrated that in the native region these morphological criteria break down, little support remains for recognizing them as separate species. Introgression results in the obliteration of fruit size differences in what would otherwise be considered *L. esculentum* according to progeny tests (Figs. 1 and 7) and to observations of original collections of what are arbitrarily called *L. pimpinellifolium*. The corolla lobe criterion—a tenuous difference at best—likewise intergrades in this material. Naturally occurring forms thus provide a continuous series of morphological gradation between the two entities.

Objections might be raised to the above comparisons on the grounds that the effects of introgression are being measured in cultivated material and that the long history of land utilization by man in this region has produced an artificial situation favoring interspecific hybridization. Such objections cannot be disproved with present evidence. We have no means of demonstrating what the genotypes of native tomatoes might have been like in this region 4,000 years ago. It is doubtful, however, whether the insect pollen vectors were less abundant then, for the continuous existence there of the self-incompatible green-fruited species depended upon their activity. It is not likely that large-fruited *L. esculentum* existed then (Jenkins, 1948), but var. *cerasiforme* is presumably native. From the standpoint of distances, the opportunities for hybridization should have been even greater than at present, for, without irrigation of the coastal plains, mesophytic vegetation would have been confined to the mostly very narrow coastal river valleys of northern and central Peru, although conditions probably favored wider dispersal in coastal Ecuador as at present. According to these speculations, the former environment probably also favored frequent cross-pollination.

This evidence casts doubt upon the separation of *L. esculentum* and *L. pimpinellifolium* as two species. Treatment of the latter as a subspecies or variety of *L. esculentum* might be more in keeping with the facts.

Relationships With Other Species

This survey has presented evidence for the contention that gene exchange occurs between *L. esculentum* and *L. pimpinellifolium*, sublimating in extensive reciprocal introgression of traits into both entities. But the zone of cultivated tomatoes also overlaps the ranges of three additional tomato species: (1) *L. hirsutum* f. *glabratum* C. H. Mull. in Ecuador, (2) *L. peruvianum* (L.) Mill. in

coastal Peru and northern Chile, and (3) *L. chilense* Dun. in southern Peru and northern Chile. The opportunity for cross-pollination with certain of these species is probably as great as that with *L. pimpinellifolium*. All of these wild forms are naturally green-fruited and differ otherwise from *L. esculentum* in a much greater array of characters than does *L. pimpinellifolium*. I have analyzed F_2 and later generations of hybrids between each of these species and *L. esculentum* and from this experience can state that the species-differentiating characters segregate on a bewildering scale. If subsequent introgression takes place to any appreciable extent, it should be revealed morphologically.

L. esculentum can be readily hybridized with *L. hirsutum* f. *glabratum* if the former serves as female parent (MacArthur and Chiasson, **1947**; Sawant, **1958**). This wild species occurs within the region of cultivation of *L. esculentum* in coastal Ecuador, but not so abundantly as *L. pimpinellifolium*. In my cursory travels in this region I found the two species cohabiting in only one location, but encountered at least **8** instances of cohabitation of *L. esculentum* and *L. pimpinellifolium*. If the extent of morphological variation of *L. esculentum* in the region of sympatry with *L. hirsutum* f. *glabratum* is compared with that of the allopatric region, no trait in the sympatric range could be safely construed as introgressive from the latter species.

Turning now to sympatric distributions with *L. peruvianum* and *L. chilense*, we find a greater opportunity for cross-pollination. In many regions throughout the coast of Peru and northern Chile I have seen plants of these species actually intermingling branches with those of cultivated tomatoes. The existence of insect pollen vectors and their effectiveness in cross-pollinating tomato species has been well demonstrated by present and other (Rick, **1950**) evidence. But, as in the case of *L. hirsutum*, comparisons fail to reveal any morphological influence of one species upon the other. The presence of *H* in progenies of *L. esculentum* from southern Peru (**131-9b** and **303**) might be construed as an exception to this statement, for the large trichomes are likewise absent in *L. peruvianum* and *L. chilense*. The possibility of coastwise exchange of tomato seeds to introduce *H*-bearing lines of *pimpinellifolium* origin from the coast of central and northern Peru, however, cannot be excluded. The apparent ineffectiveness of these two species to hybridize with cultivated tomatoes, despite the great opportunity for cross-pollination, must be explained by the extreme barrier to normal seed formation in such hybridizations (MacArthur and Chiasson, **1947**; Rick and Lamm, **1955**). Sterile culture is required to tide most embryos over the late stages of development as a result of inadequacy of the endosperm. Even with this artificial aid, the yield of viable seedlings in terms of numbers of flowers pollinated is remarkably low. Also, even if F_1 hybrids could become established in nature, they would suffer a great reproductive disadvantage because their seed fertility is only 10% or less of that of the parent species.

Thus within the limits of my field experience and studies of pedigree progenies, no certain evidence of gene exchange has been revealed between *L. esculentum* and the green-fruited species. The same conclusions apply to my search for evidence of exchange between them and *L. pimpinellifolium*, although my experience with the latter species has been restricted to much less material.

Origin of the Cultivated Races

Although the present work reveals the importance of hybridization with *L. pimpinellifolium* in the origin of culti-

vated tomatoes of western South America, it sheds little light on the larger problem of the origin of cultivated tomatoes in general—a problem that has been approached by Jenkins (1948). After weighing all available historic, ethnological, botanical, and genetic evidence, he concludes that, although the ancestral form (probably var. *cerasiforme*) very likely originated in the Peru-Ecuador area, it spread from there to southern Mexico, where first domestication and improvement probably took place.

During the course of the present studies I had frequent opportunity to inquire into archaeological and ethnological evidence bearing on the antiquity of cultivated tomatoes in South America. I was able to examine original materials and to consult with several competent authorities. No facts that I encountered would essentially alter Jenkins' hypothesis. Brief mention is made of the desultory use of small-fruited tomatoes in the early writings (Cobo, 1891–93; Guaman Poma, 1587), but there is no reason to assume that these were different from existing wild species. Archaeologically, despite the myriad representations of potatoes, maize, peppers, peanuts, cucurbits, and other cultigens, apparently no unequivocal images of tomatoes have been discovered in the existing large collections of pottery, fabrics and other artifacts.

In regard to contemporary cultivated tomatoes of western South America, the range of variation is admittedly enormous. They probably constitute the most diverse group of races to be found anywhere in the world. No attempt was made in the data presented here to characterize all the different races, although the samples presented give some insight into the nature of variation in certain parts of this region. Not only do the races differ greatly between areas, but also, the genes in certain races, apparently the minority, are even fixed in homozygous condition. The argument might then be raised that sufficient time has not elapsed for all this complex pattern of variation to have evolved if it all traces to post Columbian introductions of cultivated tomatoes.

In view of the following considerations it seems reasonable that this differentiation could have taken place within a fairly short time. In the first place, the breeding systems of tomatoes in this region favor very rapid genetic changes in population structure. Outcrossing occurs on a scale sufficiently large to permit considerable gene exchange between cultivated and wild forms and between cultivated forms. Yet, the majority of zygotes arise from self-fertilization, which leads to very rapid fixation of genes in homozygous condition. Secondly, the problems of seed storage enforce a rapid turnover of generations. Climates of most world tomato-producing areas permit seed storage for periods of several years; consequently, a new generation of plants is not necessarily produced each year. In the region in question, however, the tropical climate reduces seed viability so rapidly that ordinary storage for short periods—even from the harvest of one season to the sowing of the next—is precarious. A new seed crop must be produced each year, guaranteeing the production of a new generation each year. A third factor that undoubtedly promotes regional differentiation is the widespread practice of the native farmers to save their own seed. It is conceivable, therefore, that with the introduction within the past 200 years of several improved cultivated tomatoes—including, say, one with large multilocular fruits and another with pear-shaped fruits like var. San Marzano—the native mode of reproduction including introgression with *L. pimpinellifolium* could have given rise

to the present array of cultivated races in post Columbian times.

SUMMARY

New evidence is presented of frequent hybridization between plants of cultivated tomatoes (*Lycopersicon esculentum*) in Ecuador, Peru, and northern Chile. Hybridization between them and the wild *L. pimpinellifolium* is also suggested in the northern part of this range. The rates of natural cross-pollination in southernmost Peru were measured directly by genetic progeny tests. The values in two sets of data—25.7 and 14.8%—are in keeping with previous estimates for Peru and are five to 25 times higher than those of temperate tomato-producing areas.

An unusually high level of hybridization is also reflected in the variation of progenies from single plants and determined by genes of known monogenic segregation. In a series of 34 such progenies, 18 showed single-gene segregations, and a corresponding variability was observed for quantitative traits. It is likely that part of this variability results from hybridization with, and introgression of traits from, *L. pimpinellifolium*. Especially significant among such traits is the leaf distortion conditioned by *cm*, a gene that is present in some races of *L. pimpinellifolium* and nearly all tested cultivated forms of *L. esculentum* from coastal Ecuador, yet, with one exception, is unknown in any other cultivated tomatoes of the world. The characteristic effect of this gene is masked by the environmental conditions of the native region. The *cm* gene has been incorporated in most cultivated tomatoes of that area presumably because it enjoys some strong selective advantage. A survey of accessions of *L. pimpinellifolium* reveals similar evidence for the introgression of *esculentum* genes.

Despite cohabitation of *L. esculentum* with three additional tomato species, no evidence of hybridization with them was observed.

The results of this inquiry are discussed in respect to the systematic relations between *L. esculentum* and *L. pimpinellifolium* and to the derivation of the cultivated tomatoes of western South America.

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Arundo donax—Source of Musical Reeds and Industrial Cellulose

Arundo donax has played an important role in the culture of the western world through its influence on the development of music. Reeds for woodwind musical instruments are still made from the culms, and no satisfactory substitutes have been developed. This grass has also been used as a source of cellulose for rayon and considered as a source of paper pulp.

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Introduction

The grass family is well known as a source of many important economic plants. The cereal grains form the most important source of food for mankind and grains and forage types provide the complete diet of many domestic animals. Sugar cane is the principal source of sugar. Bamboos are widely utilized in tropical and subtropical areas and many species of grasses are employed as lawn plants. Several grasses, notably esparto, are used for the manufacture of paper, species of *Cymbopogon* and *Vetiveria* provide essential oils, and the seed heads of broom corn provide raw materials for the manufacture of brooms.

From the viewpoint of the quantity utilized or its monetary value, *Arundo donax* L. is a grass of relatively minor importance, but this plant has played an important role in the culture of the western world through its influence on the development of music. The plant has a long history, perhaps as long as that of any other species with the exception of the basic food plants. Its utilization in the creation of music can be traced back 5,000 years.

The plant was well known to ancient peoples of the Middle East. The term "reed" is of frequent occurrence in the Bible, and at least some of these references allude to *Arundo donax*. Biblical writers provide little information as to the utility of the plant but by simile made use of its well-known characteristics, its tenacity, rigidity, vigor and the nature of its surroundings in expressing their ideas or in creating imaginative descriptions of phenomena of their day.

Today, reeds for woodwind musical instruments are still made from *Arundo donax* culms, the same material that has been employed throughout the history of these instruments. This is a rather unusual case in which modern technology has been unable to develop a satisfactory substitute although, during times of shortages, much effort has been expended in this direction and, from time to time, musicians have turned in desperation to a variety of other materials.

A considerable quantity of the grass has been used as a source of cellulose for rayon manufacture, and the plant has received consideration as a source of paper pulp.

Botany

The genus *Arundo* of the family Gramineae, tribe Festuceae, includes about six species of which *A. donax* L. is the most widely distributed and the best

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known. *A. conspicua* Forst., a native of New Zealand, is widely grown in European gardens as an ornamental. *A. pliniana* Turra is native to the countries bordering the Mediterranean Sea and is utilized to a limited extent for forage. *A. formosana* Hack. is native to Formosa; *A. fulvida* J. Buch. and *A. richardi* Endl. are native to New Zealand.

Common Names. Because of its widespread distribution and extensive utilization by man, *Arundo donax* has assumed many common names. In the southwestern United States, the plant is sometimes called by the Mexican name *carrizo*. In English-speaking countries in general, it is called bamboo reed, Danubian reed, donax cane, giant reed, Italian reed, Spanish reed, or Provence cane, as well as by such general appellations as cane, reed, or bamboo.

In other countries, the most widely employed names are merely translations of the simple epithets "cane" or "common cane". The most important names, some of which are applied also to *Phragmites communis*, are as follows: Burma: alokyu; Egypt: kasab; France and French Africa: canne, canne de Provence, roseaux; Germany: Pfahlrohr, Pfeilrohr, Riesenschilf; Greece: kalamós; India: bara nal, gaba nal, narkul; Italy: calami, caneviera, canna, canna berganega, canna di cannitu, canna commune, canna domestica, canna montana, canna da rocchi, canna di stenniri, ciane gergane, donaci, gutamu, virtamu; Spain and Spanish speaking countries: cana comun, canna de Castilla.

In Italy, the form with variegated leaves is known as *canna zagariddara*.

With several exceptions in which the meaning will be clear from context, the term "reed" is employed in this paper only in reference to the sounding mechanism of a musical instrument.

Description. *Arundo donax* is a tall, erect, perennial, cane-like or reed-like grass, 2 to 8 m. high. It is one of the largest of the herbaceous grasses. The fleshy, almost bulbous, creeping rootstocks form compact masses from which arise tough fibrous roots that penetrate deeply into the soil. The culms reach a diameter of 1 to 4 cm. and commonly branch during the second year of growth. They are hollow, with walls 2–7 mm. thick, and divided by partitions at the nodes. The nodes vary in length from approximately 12 to 30 cm. The outer tissue of the stem is of a siliceous nature, very hard and brittle with a smooth glossy surface that turns pale golden yellow when the culm is fully mature. The leaves are conspicuously two-ranked, 5 to 8 cm. broad at the base, tapering to a fine point. The leaf sheaths are tightly wrapped around the stem and often persist long after the blades have fallen. The flowers are borne in large, terminal, plume-like panicles 30 to 60 cm. long.

Morphologically, *Arundo donax* is comparatively uniform. A variegated variety of the species, known only in cultivation, was described in Miller's Gardener's Dictionary in 1768. This form is now known as *A. donax* var. *versicolor* (Mill.) Kunth, and in most respects is a diminutive of typical *A. donax*. In its most familiar form, this variety has culms up to 1.5 cm. in diameter that reach a maximum height of 4 to 5 m. but are frequently but .6 to 1 m. high. This plant produces a more dense growth than does typical *A. donax* due to a greater production of culms as well as to a greater production of leaves and is less hardy than the latter. By selection of off-shoots other variegated forms have been propagated that do not differ significantly from typical *A. donax* except for their variegated leaves.

Cane grows very rapidly. Growth at a rate of .3 to .7 m. per week over a period of several months is not unusual when conditions are favorable. Young culms develop at approximately the full

diameter of mature cane, but their walls increase in thickness after the initial growing season. The new growth is soft and very high in moisture and has little wind resistance.

Distribution. *Arundo donax* is native to the countries surrounding the Mediterranean Sea. From this area, it has become widely dispersed, mostly through intentional introduction by man, into all of the subtropical and warm-temperate areas of the world. In many areas it has become well established. The plant is abundant in India, ascending to elevations of 8,000 feet in the Himalayas, and has been dispersed eastward to Burma and China. The species appears to be absent from central Africa but has been successfully introduced into the southern part of that continent. It has been introduced into Australia and many islands of the Pacific and Atlantic oceans.

Donax cane has also been widely dispersed in the New World, from the southern United States southward through Central and South America. It occurs in most of the islands of the West Indies, as well as in Bermuda and the Bahamas. In the United States, the plant has been cultivated successfully as far north as Washington, D. C., and escapes from cultivation as far north as Virginia and Missouri. It has been widely planted, often as an ornamental, throughout the warmer states, especially in the southwestern part of the country where it is used along ditches for the prevention of erosion. There are abundant wild growths along the Rio Grande River.

The cultivation of cane for woodwind reeds has been largely limited to a very small area in southeastern France in the adjoining Departments of Var and

FIG. 1. A cultivated cane brake (*Arundo donax*) in California. (Photo courtesy of Arnold Brilhart)

FIG. 2. A small ornamental planting of *Arundo donax* in California. This species is commonly used as an ornamental in the warmer sections of the United States. (U.S.D.A. Photo)

Alpes Maritimes. Cane has also been cultivated for this purpose to a small extent in Texas and California. Cultivation of the plant for use as a source of industrial cellulose has been largely limited to northern Italy. Donax cane is widely cultivated, on a small scale for local use, in Italy and other countries around the Mediterranean Sea.

Ecology. *Arundo donax* tolerates a wide variety of ecological conditions (**10**, **14**, **27**, **28**, **35**, **42**). It is reported to flourish in all types of soils from heavy clays to loose sands and gravelly soils. It tolerates excessive salinity and will survive extended periods of severe drought accompanied by low atmospheric-humidity or periods of excessive moisture.

The plant produces the most vigorous growth in well-drained soils where abundant moisture is available; its favored environment is along the border of lakes or along ditches and canals. Along the Rio Grande the most abundant growths occur on fertile soils well above the river bed that become flooded only during rare flash floods. Very little cane grows at lower levels (**14**).

The plant's ability to tolerate or grow well under conditions of apparent extreme drought is due to the development of coarse drought-resistant rhizomes and deeply penetrating roots that reach deep-seated sources of moisture. Cane can be seriously retarded by lack of moisture during its first year, but drought does not cause grave damage to patches 2 to 3 years old. From the standpoint of moisture requirement cane produces satisfactory growth in areas that are suitable for the cultivation of corn (**28**).

Arundo donax is a warm-temperate or subtropical species. When dormant, it is able to survive very low temperatures but is subject to serious damage by frosts that occur after the initiation of spring growth. The plant does not flourish under true tropical conditions.

In nature, cane is able to flourish on soils that are apparently very infertile. Under cultivation the plant is responsive to improved soil fertility and is particularly favored by abundant nitrogen. In soils of low fertility, especially those lacking in nitrogen, the buds of the rhizome are produced at a greater distance apart than in fertile soils and there is much greater expansion of the underground structures. In Argentina, annual cane yields in infertile, partly fertile and fertile soils were 4, 6, and 8 tons, respectively, of dry cane per acre (**28**).

This species does not produce viable seed in most areas to which it is apparently well adapted. However, plants have been grown from seed collected in Afghanistan, Baluchistan, and Iran.

Anatomy. *Arundo donax* stems exhibit typical monocotyledonous structures (**16**, **27**, **40**). Although the vascular bundles are distributed freely throughout the cross-sectional area of fundamental parenchyma, those toward

the periphery of the stem are smaller and more numerous than are those toward the interior. The vascular bundles are collateral and are surrounded by one or more rows of thick-walled, strongly lignified fibers. These fibers are long and narrow and taper to a fine point. The larger bundles of the interior are commonly enclosed by a single row of fibers. Toward the periphery of the stem, as the size of the bundles decreases, the number of rows of fibers associated with the bundles increases. Near the exterior of the stem, where the bundles are small and comparatively close together, the fibers are sufficiently abundant to form a continuous ring of structural tissue within which are scattered the vascular elements. This structural ring is separated from the epidermal layer by a narrow band of parenchyma cells that in mature stems are comparatively small, thick-walled, and lignified.

The vascular bundles, with the exception of those near the periphery of the stem, are embedded in thin-walled parenchyma the innermost cells of which are very large with inter-cellular spaces at their angles.

The vascular bundles, including the associated fibers interior to the structural fibrous ring, occupy approximately 24% of the total cross-sectional area of the stem. The vascular tissue and associated fibers that compose the structural ring make up approximately 33% of the total cross-sectional area. Thus, parenchymatous tissue occupies but 43% of the cross-sectional area of the stem.

The single layer of epidermal cells is covered with a waxy cuticle. In the tangential plane, the walls of most of these cells form a strongly sinuous outline. Scattered through the epidermis are short-roundish or irregularly shaped cells and typical gramineous stomata.

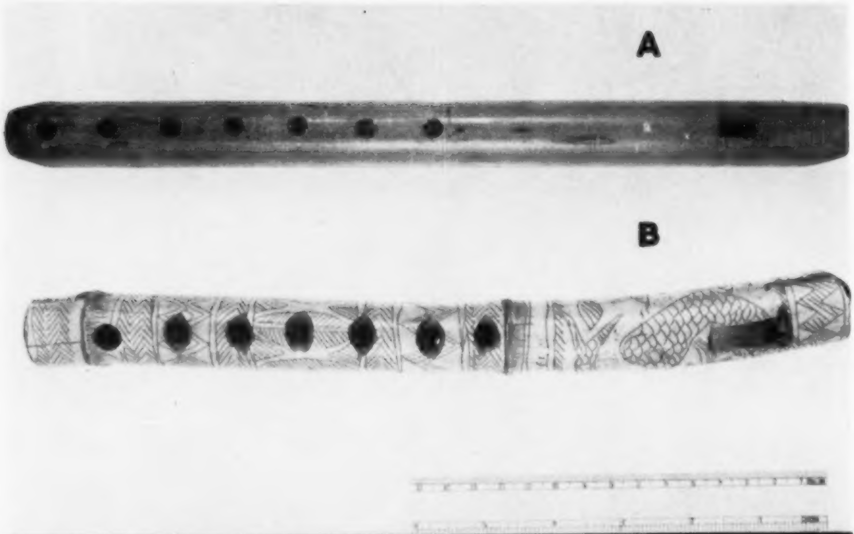
Both leaves and stems of *Arundo donax*, particularly the former, contain numerous highly silicified cells. These cells are associated with the vascular bundles and are also located in the epidermal tissue. Their presence explains the relatively high silica content that has been indicated by chemical analyses.

Utilization: Reeds for Musical Instruments

Fundamentally, woodwind instruments consist of a tubular or conical resonator within which sound waves are generated by the vibrations of a reed, as for the clarinet or oboe, or by the passage of a stream of air against the edge of a small aperture in the tube, the manner of sounding the flute. The tone generated by a woodwind is a function of the length of the resonator and is controlled by opening one or more of a series of apertures.

Reeds for modern musical instruments are of three types. The single beating-reed, employed with clarinet and saxophone, consists of a tongue or strip of cane, thinned gradually at one end to a broad delicate tip. The base of the reed is clamped to a mouthpiece with the thin vibrating blade overlapping an opening which leads into the resonator. When at rest, the reed is positioned in such a manner that there is a slight space between the blade and the mouthpiece. When played, the reed vibrates or beats against the mouthpiece. The double beating-reed, employed with the bassoon and oboe, consists of two pieces of cane arranged back to back. When played, the thin blades of the two elements vibrate against each other. Reeds of both types are used in modern bagpipes although the single reed for this instrument differs somewhat from that described above. The free-reed used in the mouth organ, reed organ, and concertina consists of a thin metal element which vibrates freely through an arc and does not beat against any part of the instrument. *Arundo donax* has apparently not been used at any stage in the

FIG. 3. A well-developed rhizome system of *Arundo donax*. (U.S.D.A. Photo)



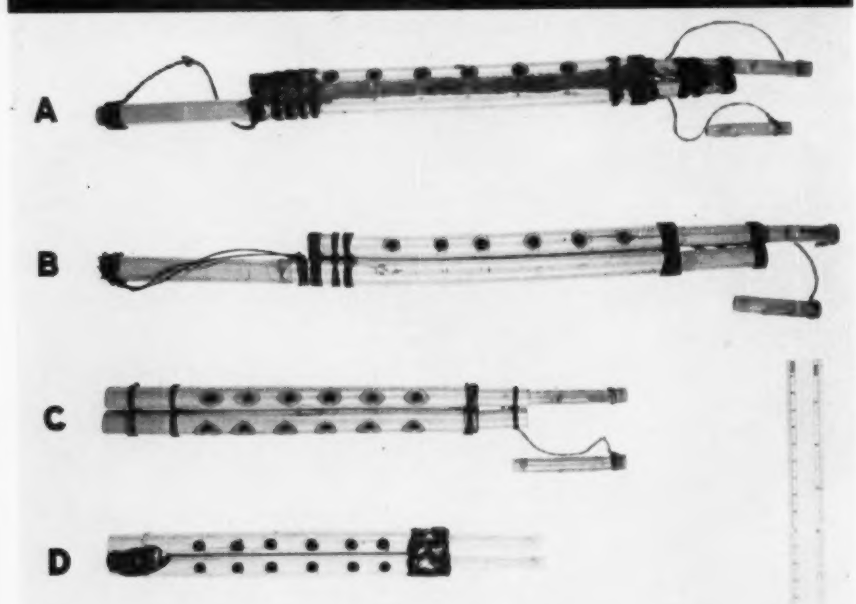


FIG. 4 (Above). Modern whistle- or fipple-flutes formed from *Arundo donax* cane. Each pipe is closed at the lower end by a node. The upper end is fitted with a plug in which a sound hole has been cut. A thumb hole is located on the reverse side of each pipe opposite the upper-

development of the free reed and consequently this type is not further discussed in the present paper.

History

In the music world today, *Arundo donax* is most familiar as the source of raw material for the manufacture of reeds for woodwind instruments. The origin of donax cane as a material associated with musical instruments is surprisingly linked, not with an ancestor of one of the above instruments, but with a primitive ancestor of the flute (5, 7). That a hollow tube could be made to produce a characteristic sound and that hollow tubes of varying lengths could be made to produce different sounds could hardly have gone long unrecognized by primitive man. Thus, the opportunity for the discovery of the primitive woodwind has long been before man, whether as a hollow bone or as a tube of bamboo or donax cane.

It would be difficult to estimate the earliest date at which canes of *Arundo donax* were first used for making flutes. Relics of the early Stone Age show that man knew how to form a single-toned pipe from bone. The earliest type, the nay, or vertical form, was closed at the base and sounded by blowing across the open end of the tube. Later, pipes were sounded by blowing across an aperture placed just below the closed upper end of the tube and were held in a horizontal position. By the late Stone Age the bone flute had been improved by the addition of one or more finger holes resulting in an instrument that could sound several notes. Early man soon discovered that a much more satisfactory instrument could be fashioned from a tube of vegetable material. Around the Mediterranean basin canes of *Arundo donax* were the classical raw material for this purpose, and their use originated independently of the use of bamboo for the same purpose in the Orient and islands of the south Pacific and the use of other materials in North and South America. Primitive flutes or flute-like instruments appear to have been developed by most primitive peoples.

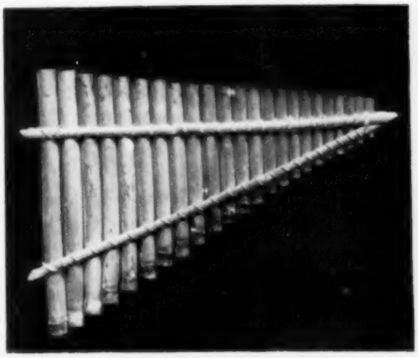


FIG. 6. Modern Egyptian Pan pipe constructed of *Arundo donax* cane. Each tube is closed at the base by a node and lashed to the cane cross-pieces and adjacent tubes with cord. The instrument is played by blowing across the open ends of the tubes. (Photo courtesy of Smithsonian Institution)

From the most simple vertical flute, it

most finger hole. A. Moroccan flute. B. Egyptian flute, ornamented with incised designs filled with black pigment. (U.S.D.A. Photo, instruments from Smithsonian Institution collection)

FIG. 5 (Opp., below). Modern eastern-Mediterranean double-pipe single-reed instruments, reeds and resonators formed from *Arundo donax* cane. These instruments do not differ appreciably from pipes employed several thousand years ago in Egypt and Mesopotamia. Each reed is formed from a hollow piece of cane, stopped at one end by a node. A horizontal slit is cut into the tube, penetrating into the cavity, to form the vibrating tongue or reed. A. Syrian urgun. The pipes are cemented together with wax and lashed with waxed cord. The unperforated drone-pipe, below, sounds but a single note. B. Egyptian arghool. The pipes are lashed with waxed cord. C. Syrian naigha. Each of the melody pipes is fitted above with an extension. D. Iraqi cane instrument. The two melody pipes are cemented together with bitumen. (U.S.D.A. Photo, instruments from Smithsonian Institution collection)

was but a simple step to the development of the Pan pipe or syrinx. This primitive instrument consisted of from several to as many as 25 pipes, varying in length from three to approximately ten inches, each sounding a different note. The tubes were arranged so that their open ends were in a horizontal row and were attached, each to its neighbor or to one or two cross pieces, by a crude twine or adhesive. The Pan pipe was typically constructed from culms of *Arundo donax*, the stopped ends of the tubes formed by joints of the cane. Pan pipes have persisted as folk instruments in the present culture of southeastern Europe and are still made of donax cane.

The Pan pipe is believed to have formed the basis for the origin of the most primitive pipe organ. The earliest organ of record, dated at approximately 200 B.C., is comparatively complex and a far cry from the Pan pipe, but was referred to by Greek writers of the time as a syrinx or as a syrinx played by hand. The primitive organ provided a mechanism for creating a wind supply and included a wind chest, to which flue pipes of donax cane were attached. Additional mechanisms were provided to permit the passage of air through the pipe, or pipes, of the musician's choice. The appropriate note for each pipe was created by the vibrations resulting from the passage of air against the edge of a slit cut into each cane tube. As the evolution of the organ progressed, the craftsman abandoned *Arundo donax* cane for tubes of wood or metal.

While the earliest stages of the development of the flute can be found in relics, early pictorial records, and among instruments in use by primitive peoples of the world's present population, early stages in the evolution of instruments sounded by a reed are not very well known (5, 7, 20, 33). The mechanism of the double reed may have been discovered when primitive man compressed the end of a pliable hollow stem between his teeth and created a non-musical flutter with the pressure of his breath. Or possibly, the principle of the double reed was recognized when man first forced his breath between two blades of grass. The most primitive type of single-reed mechanism was a squeaker of hollowed cane or other plant material with a long rectangular section raised from its surface to create a vibrating tongue. The first reed of this type was thus continuous with the resonator. A vibrator so attached to the "mouth piece" is referred to as an idioglottal reed. Whether the double or the single reed is the primitive type is not known, but it appears likely that the double reed came first or that both were developed at about the same time. As we know it today, the double reed is far more complex in structure and manufacture, but it is actually less complex in its origin and evolution.

The first significant development following the origin of the simple squeaker was the use of a longer tube perforated with one or more finger holes to vary the tone. When the fragile reed became damaged or worn, it was necessary that the entire instrument be discarded. As the craftsman began to devote increased attention to the perfection of the resonator, the need for a reed attached to a separate mouthpiece became evident; an arrangement that would provide for replacement of the reed but permanent use of the improved resonator was necessary. This second important improvement closely followed the adoption of the longer perforated tube.

A majority of primitive peoples of the present day are ignorant of reed instruments. Although the reed mechanism, as a simple squeaker, may have been developed independently by different primitive peoples, the initial stages apparently did not give rise to further development except in Egypt and south-

western Asia. Advanced instruments of this type have been discovered in the hands of primitive peoples in various parts of the world, but in most instances it is possible to attribute the invention to the early peoples of the middle East.

The factors primarily responsible for this origin are the unique characteristics of *Arundo donax* which make it the finest raw material for formation of the reed mechanism and the original geographic distribution of the plant around the Mediterranean Sea and along the Nile. Thus, of the early civilizations, only those of Egypt and Arabia had available the one material that could be most effectively developed. Throughout the entire period that reed instruments were under the influence of north African or southwestern Asiatic peoples, donax cane provided the preferred raw material for the reed and the most easily adapted and most favored material for the resonator as well. The structure of the cane, apparently unique among plant materials, has provided a substance with ideal characteristics of resilience, elasticity, and resistance to moisture. It forms a superb vibrator that responds instantly to minute changes in pressure and does not crack or split under the adverse conditions of intermittent but frequent contact with moisture.

Archeological evidence indicates that the reed woodwind, as a musical instrument rather than as a simple squeaker, originated in Egypt or in Mesopotamia. At the earliest point in history at which we have evidence of the existence of these instruments, their use was already well established in the life of these peoples. Our knowledge of these early woodwinds is based upon discoveries from Egyptian tombs and ruins of early Sumerian cities in southeastern Iraq. The oldest representations have been found in the painting and sculpture of the Egyptians, the most ancient literary references in the cuneiform writings of the Sumerians.

The first Egyptian reed-woodwind on record was a single tube of cane with finger holes. Pipes of this type are known to have been in use before 3,000 B.C. and by this time, both single and double reeds had probably been developed. Double pipes consisting of parallel cane tubes held together by wax or bound with string were also in use. Each pipe was equipped with a vibrator, both of which were placed in the mouth to sound the instrument. These tubes were each perforated with finger holes, but probably sounded the same or nearly the same notes. Representations of Egyptian double-pipe instruments have been identified on sculpture dated about 3,000 B.C.

In Mesopotamia, the double-pipe instrument was modified to form a V-shaped double pipe, probably played with two single reeds. This is the most familiar type in early paintings and sculpture. Ebony, bronze and silver, as well as cane, were used for the resonator. An idioglottal reed was cut into a detachable mouthpiece or in the case of some cane instruments cut into the end of the resonator. Some of the double pipes had an equal number of finger holes in each tube. Others had only one tube with perforations, the unperforated tube sounding a single tone unless furnished with extensions. About 1600 B.C., the V-shaped double pipe was carried back into Egypt and from this period on is represented in profusion on Egyptian sculpture, almost to the exclusion of other types.

These primitive instruments, changed but little from the early Egyptian pipes from which they descended, are still in use in Egypt and throughout the Moslem world.

The Moslems were largely responsible for the dispersal of the reed woodwind. They spread the pipe into China,

FIG. 7. Modern Moroccan reed instrument constructed of *Arundo donax* cane, tin plate, and cow's horn. The single reed is an idioglottal primitive-type like those shown in Fig. 5. (U.S.D.A. Photo, instrument from Smithsonian Institution collection)

the East Indies, Europe and North Africa, and indirectly, through the early Spaniards, to the Americas.

The Egyptian-Arabian pipe spread to Crete and then to Greece when Crete was invaded by the Greeks about 1,100 B.C. The earlier Greek pipes were mostly double-reeded. The single-reed type was not used until about 300–400 B.C., although the Greeks were apparently long aware of the single-reed mechanism.

The first important changes in the musical pipe since its initial development by the Egyptians and Arabians 3,000 or more years previously were brought about by the Greeks. The mouthpiece, previously employed with the hinge of the idioglottal reed toward the player, and engulfed completely in the mouth, was altered so that the hinge of the reed was away from the lips. The instrument was played with the lips pressed against the reed. As the position of the lips changed, the length of the vibrating tongue could be varied, altering the fundamental pitch of the pipe. In addition, the Greeks varied the length of the mouthpiece and gradually increased the number of finger holes to as many as 16 in some pipes. As the number of finger holes increased, a system for closing chosen holes of the resonator was devised by use of metal bands held in place by rings encircling the tube. The bands were perforated and arranged so that various finger holes could be partially or completely covered or left open.

With the overthrow of the Greeks during the middle of the second century B.C. by the Romans, the musical pipe was carried to Rome. Little change resulted although the resonator came to be made of bone, wood, or metal as well as of cane. With the decline of Roman culture, during the fifth century A.D., the reed pipe as then known and its science disappeared.

During the Dark Ages, all musical instruments were frowned upon by the Church and the use of the highly developed reed woodwind died out in Europe. As modified by the Greeks and used by the Romans, this pipe was a very intricate instrument, not a simple folk instrument like the early form developed by the Egyptians and Arabians. Performance on the pipe was a real art and thus required the attention of a true artist. It was far too complicated for survival during this period in the hands of the peasant. This highly developed instru-

ment was thus an end line of evolution, completely submerged by the darkness of the Medieval Age, an extremity of a branch of the family tree whose main trunk was to culminate in the modern reed-woodwind.

For the origin of our modern reed instruments we must return to the primitive pipe developed by the Egyptians and Arabians. Of the many folk instruments of the reed-woodwind type that date from medieval times, some of which are in use today, most can be traced to an origin in southwestern Asia. A Sardinian instrument made from three cane tubes has evolved from a primitive instrument brought to Sardinia by the Phoenicians about 500–700 years B.C. Reed instruments were also brought to Europe by the Moors who overran Spain and part of France between 700 and 800 A.D. and who held on in Spain for an additional 700 years. A folk instrument of cane used in the Balearic Isles may be a relic of this invasion. Knowledge of the reed woodwind possibly reached the British Isles as a result of communication between Moorish Spain and Wales. It is possible, however, that the primitive British and Balearic types developed as a result of earlier Celtic migrations. Migration to the west eventually spread the knowledge of the reed instrument throughout a large part of Europe.

From this widely distributed, simple, primitive woodwind, our modern clarinets, oboes, bassoons, etc., have evolved. During the years following the dawn of the Renaissance other musical instruments became widely established, but the woodwinds were hardly known. The tones produced by these instruments were oriental in nature, sensitive, piercing, whining tones that appealed to eastern rather than western ears. In addition, these instruments had associated with them certain acoustical problems which were not to be solved until many years later.

Up un il his time, the woodwind had been mo. consistently made of cane. The reeds were typically idioglottal though frequently cut into cane mouthpieces and used with resonators of other materials. As the use of these instruments spread farther north into Europe, farther from the native home of *Arundo donax*, it became necessary to employ other raw materials. For the resonator, boxwood and other European woods came into use. The use of such nonvibrant raw materials was followed by the development of the heteroglottal reed (not continuous with the mouthpiece, but attached to it by string, hide, or other material). Many materials were used for the vibrating tongue but over the centuries, none proved so satisfactory as donax cane.

During the 17th to 19th centuries, the single-reed-type instrument was improved and developed into a family of many instruments including the true 18th century clarinet and 19th century saxophone; the double-reed type, evolved into the oboe, English horn, and bassoon and their relatives.

The layman generally does not recognize the bag pipe as a reed instrument, although this woodwind employs both single and double reeds prepared from stems of donax cane. The bag of this instrument serves as a flexible wind chamber from which the expulsion of air is controlled by pressure of the musician's arm. Air is supplied by a bellows carried under the opposite arm or by blowing into a tube connected to the bag. One to four reeds are completely enclosed within a comparable number of tubes which are attached to one end to the bag. One pipe, the chanter or melody pipe, encloses a typical double reed and is equipped with holes or keys to vary the tone. The remaining pipes, the drones, enclose idioglottal single reeds, and, lacking a mechanism for varying the tone, sound but a single

note. Control is not exercised over the pipes independently; all operate in unison.

The single reed of the bag pipe is of special interest, for even in the most modern pipes, this reed does not differ from that employed in the most primitive single-reed instruments developed some 5,000 years ago. A single reed for this instrument is prepared from a slender tube of cane, closed at one end by a joint, by cutting transversely into the hollow of the cane to a depth of about 2 mm. and then raising a tongue in the side of the tube by cutting longitudinally for a distance of about 5 cm.

The most primitive bagpipe on record was employed by the Romans during the reign of Nero, but the principles of the instrument were known at a much earlier date. During at least a part of the early history of the instrument, donax cane was used for reeds. As the use of the instrument passed to the north, far removed from the native home of *Arundo donax*, other materials were employed. The use of cane was renewed at an undetermined date when supplies of this material were made available by improved transportation.

Today, one can only speculate as to what would be the nature or quality of our music, both classic and modern, had not *Arundo donax* been available to the early civilizations of Egypt and southwestern Asia and the later civilization of Europe. Undoubtedly, the initiative of the early artisan would have culminated in the successful application of another material to the making of reeds. Can we comprehend the effect of such a material upon the evolution of music?

Growth Requirements

Most musicians and reed makers hold the opinion that the environmental requirements for production of quality cane are highly rigid and that there is something highly specific about the soils and atmosphere of southern France that is responsible for the production of good cane. Beyond this there is little agreement as to the most satisfactory conditions. The opinion held by some is that the cane should be grown in clay soils while others firmly believe that only loose sandy soils will produce the finest quality material. It is generally agreed that low atmospheric humidity is desirable.

The fact that good-quality reeds have been made from cane obtained from Spain, Italy, Sicily, North Africa, Kenya, South America, Mexico, Cuba, Texas, California, and Virginia suggests that soil and other conditions are not as rigid as they are generally considered to be.

Arundo donax is well adapted to a wide variety of soil conditions. With all factors taken into consideration, it appears that the most suitable habitat for the production of raw material for reeds is a deep light soil, which provides adequate moisture for maintenance of continued growth but does not contain sufficient moisture for a highly vigorous development that would result in the formation of soft porous cane. A site near the sea is regarded as preferable to a more inland location.

Cane Production in France

The production of cane for the manufacture of reeds is restricted to the coastal area of southeastern France in the Departments of Var and Alpes Maritimes, within the district formerly known as Provence. The most important plantations are in the vicinity of the coastal town of Fréjus.

Cultivation. New plantings are started by vegetative propagation. Planting material is obtained by digging and dividing old rootstocks or occasionally by rooting cuttings. Large canes may be cut in June and placed horizontally in shaded, moist, sandy soil. Young plants develop at the nodes and after reaching

a satisfactory size are separated and removed to the fields. The rhizomes or rooted cuttings are placed in rows 2 to 3 m. apart and covered with soil to a depth of about 10 cm. The plants are watered if necessary during the first year and are hoed once or twice. Until the ground becomes covered with cane, the space between the rows may be utilized for the cultivation of potatoes, beets, and other similar crop plants.

During the early development of a planting, the canes are cut periodically to encourage spreading of the rhizomes and to increase the density of the stand. Established plantings receive little attention other than the periodic removal of large weeds and the small or most inferior canes. Some growers remove leaves before harvest to allow exposure of the canes to the sun and use the foliage for animal feed or bedding.

Harvest. The new plantation requires up to five years growth before producing the first full crop of good-quality cane. In established plantations, canes to be used for reeds are selectively cut during the winter months, when they are two or three years old. During harvest, any cane that is too old for use in reed manufacture is removed to allow better growing conditions for the following year's crop.

FIG. 8. Sun-curing cane in Var Province, France. (Photo courtesy of Luther P. Hines)

Drying and Curing. Treatment of the harvested cane varies greatly and largely depends upon the opinion of the individual grower or upon the preference of the reed manufacturer for whom the cane is destined. The newly harvested canes are tied in large bundles, often

with leaves and branches intact. These bundles are stacked erect with the cane bases spread out in such a manner as to form a pyramid; they may be gathered into shocks around a post, or the bundles may be stacked erect against either side of a horizontal timber supported at a height of 2 to 3 m. above the ground.

Certain growers prefer to initiate seasoning of the cane under a tree or open shed or provide protection from the sun by covering the south side of the bundles with grass or cloth.

Cane is not harmed by rain. During the initial drying period, the leaf sheaths rot and often stain the outside of the cane, producing a mottled appearance. This does not affect the quality of the cane. In fact, mottling is regarded by some musicians as an indication of high quality. The initial drying stage requires at least two to four months during which the moisture within the cane drains out or is otherwise dissipated. Following this period the upper branching portions of the canes are removed, the remaining leaves and sheaths are cleaned away and the canes are cut into lengths of about four feet. Any spoiled or cracked canes are discarded.

FIG. 9. Curing Mexican-grown cane in Arizona. The tubes are arranged on string to facilitate handling. (Photo courtesy of J. W. Manson)

The quality stocks are next cured in the sun. The selected canes are suspended horizontally on low supports or laid obliquely along a fence, rope, or other support stretched between poles at a height of about three feet above the ground. Some growers arrange the supports so that they are oriented in a north-south direction. This is to prevent cracking of the cane and the development of an undesirable red coloration which may result from excessive exposure to the sun. As soon as the surface exposed to the sun turns to a creamy color, the canes are turned so that another surface is exposed to the sun's rays.

The cane is turned once or twice as the grower prefers. Exposing the cane in three operations is generally preferred as it results in a more uniform color. This period of curing takes at least three weeks, and a longer period is often considered more desirable.

The total period of outdoor drying varies greatly. The cane may be dried for six to twelve months, and some advocate an even longer period. In certain instances, sun drying is supplemented by kiln drying.

Following sun curing the cane is stored in sheds. It may be retained in storage for a further indefinite period of curing or immediately marketed. By the time the cane is used by the reed maker it may be as much as three to five years old. The total period of seasoning, as well as the growing period, is influenced considerably by the demands of the market.

By the time properly-seasoned cane is ready for use, it has turned to a rich golden-yellow. The cane is sectioned into tubes by cutting about 1 cm. on either side of the nodes. Tubes of poor quality are eliminated. These include tubes with walls too thin or too thick, tubes of unsuitable diameter, those that are cracked or not straight, and those that are of poor color or otherwise of inferior appearance. Tubes, in 50-pound lots, are packed in bags and shipped to manufacturers or distributors.

Yield. Estimates of the average annual yield of dry matter from *Arundo donax* vary from 3.2 tons per acre for wild stands in India (32) to 17.5 tons per acre for plantings cultivated in Italy for the production of viscose rayon (24). The latter figure can be accepted as a maximum, and some idea of the yield of cane suitable for reeds can be derived from it. Of the dry matter produced, over 50% consists of leaves and the upper branching portion of the cane that cannot be utilized for manufacture of reeds. This leaves a total production of less than 10 tons per acre from which raw material for reeds can be selected. Not more than 10% of this quantity can be used. Only a small proportion of the yield has the proper diameter, and of this, much of the cane has walls either too thick or too thin. Many canes are discarded because they are crooked, cracked, or otherwise imperfect, and a large portion of the stock is discarded when the nodes are removed.

Cane Production in Other Areas

The Department of Var in southern France is the traditional center of the production of cane to be used for reeds. Var cane was widely recognized as the only quality material, and this monopoly of the French growers was not contested prior to World War I. As a result of the war, cane shortages in other parts of the world became acute and the shortage persisted for several years. It was reported that during the war years, Senegalese troops billeted among the French cane fields, consumed enormous quantities of cane for fuel and construction of shelters, and were responsible in part for the later shortages of cane and its poor quality. As a result of the wartime and post-war shortages, musicians in the United States made limited efforts

to establish domestic sources of cane. Small plantings were established in California, Texas, Georgia, and Alabama; some were from rhizomes introduced from the cane plantations of southern France, and others from rhizomes of unknown origin. None of the cane from these plantings was reported to be satisfactory. Sporadic efforts were made during the decade preceding World War II to grow suitable cane in this country but without success. With the then adequate supplies available from France, the main stimulus for developing an American source slackened.

During the early stages of World War II the cane supply again became short, and renewed efforts were made to develop sources within the United States. Cane from existing plantings, mostly ornamentals or escapes, was collected and tested by musicians, reed manufacturers, and concerns previously engaged in importing cane or finished reeds. Shortly, satisfactory cane was discovered along the Rio Grande in southern Texas. As a result of this discovery several strains including materials introduced from Iran and Afghanistan by the U. S. Department of Agriculture were planted for comparison at Brownsville, Texas. Details of later progress are lacking, but the cane produced on 10 acres was reported to have been harvested in sufficient time to be made available to manufacturers by early 1942. Whether this cane was acceptable to the manufacturer is not known, but several musicians employed it successfully. This cane at $1.25 to $4.00 a pound was advertised in trade publications at the time, the price varying according to the type of instrument for which it was selected. This cane-growing operation was not successful and was later discontinued.

During this same period, considerable effort was devoted to the establishment of cane production in California with most of the same strains planted in Texas. Good-quality cane was made available to musicians, several of whom have reported that fine-quality reeds could be made from it. Cane production in California decreased considerably after World War II, as French cane again became available, but as late as 1950 one producer was advertising California cane grown from imported French stock. At present cane is being cultivated for reed manufacture by at least one grower.

The search for a new supply of cane by American musicians also resulted in the discovery of suitable quality materials in Sonora, Mexico. These naturalized growths were exploited to a considerable extent during and just after World War II. Cane was collected by one manufacturer in the vicinity of Guaymas and transported to Arizona for curing. Another concern set up a factory near Nogales to carry out the preliminary processing of local cane, and the reeds were finished in New York City. Mexican cane is currently sold in the United States, one dealer recommending it for student reed-making practice. This cane is now used to a very limited extent by reed manufacturers.

The World War II shortage of cane resulted in the successful establishment of plantations by the Russians in the Caucasian area (22). This cane is reported to have been very unreliable at first but, with improvements in methods of cultivation and seasoning, it is now a very satisfactory raw material.

Reed Making

Prior to the middle of the nineteenth century the making of all types of cane reeds was a craft practiced by specialists working alone or by the musician who made his own. With the development of

suitable machinery, the making of single reeds has been gradually converted to a mass-production basis. As double reeds are highly intricate and must be tailored closely to the specific requirements of the individual instrument and musician, their manufacture has largely remained in the hands of the individual reed maker or musician. A few manufacturers produce double reeds, principally for student use.

Cane received by the reed maker is in the form of short tubes, varying in diameter and wall thickness, cut from between the nodes of donax culms. The tubes are sorted into sizes appropriate to the instrument for which reeds are to be made. Among the single-reed instruments, the E- or B-flat clarinets and soprano saxophone require the smaller sizes; the bass clarinet and bass saxophone require the larger. Among the double-reed instruments, small-size canes are used for oboe reeds and larger ones for bassoon reeds.

Single reeds are made from cane tubes 7 to 10 cm. long and 2 to 3 cm. in diameter (36, 43). The tubes are separated into quarter sections with a cane splitter, a tool consisting of four sharp metal blades, set perpendicular to one another near the tip of a vertical shaft, in appearance somewhat like the feathers that guide an arrow. Tubes of cane are placed on the shaft and driven down over the blades with a wooden mallet. The quarter sections are carefully cut into appropriate lengths with a saw.

FIG. 10. The worker in the background is sorting cane tubes according to diameter requirements of the various instruments. The worker in the foreground is splitting the cane by driving the tubes onto a cane-splitter. (Photo courtesy of French American Reeds Mfg. Co., Inc.)

The medullar surface of the quarter section is flattened with a plane, and the cane is trimmed along the edges to the exact width of the finished reed. The quarter section is then planed on the flat surface to its final dimension. The blade is shaped by cutting away about half of the rounded epidermal surface, tapering it at one end, to an edge as thin wide. The tip of the blade is approximately .075 to .175 mm. in thickness, and the base of the blade is 3.20 to 3.65 mm. in thickness.

The finished reeds are spot-tested on an instrument, but none of the reeds to be sold can be so examined. Prior to packaging, the reeds are graded as to strength in five or more grades from very

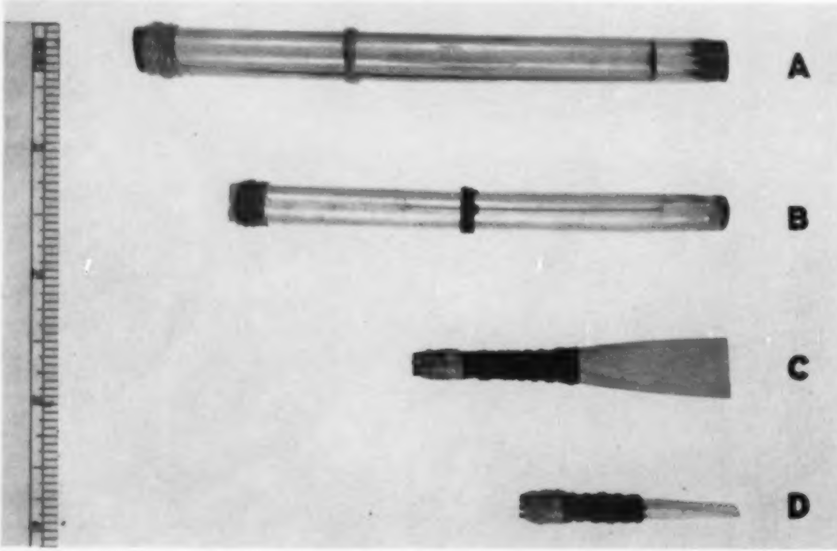


FIG. 11. Bag pipe reeds formed from *Arundo donax* cane. A and B. Base and tenor drone reeds. These single reeds do not differ appreciably from those employed with ancient Egyptian and Mesopotamian reed instruments. The cord wrapping at the base serves for tight insertion in the instrument. The upper cord wrapping can be moved up or down to adjust the tone of the reed. The reeds are stopped at the upper end by a node, the pores of which are sealed with beeswax. C and D. Double reeds for practice chanter and chanter. (U.S.D.A. Photo, reeds courtesy of William C. Stokoe, Jr.)

as paper. The portion removed is cut away by a plane passing over a jig in which the cane is set with a pattern. The surface of the blade is finished with sand paper; the paper-thin tip of the blade is filed square and then rounded off with a guillotine-like trimmer.

As an example of the dimensions of a finished single reed, a small size for clarinet is about 6.5 cm. long and 1.1 cm. soft to very stiff. This quality is more an indication of the shape and thickness of the blade and is not greatly affected by the nature of the cane from which the reeds were made.

Double-reed manufacture is considerably more complex than the manufacture of single reeds (3, 13). In contrast to the single reed, the flat surface of which is clamped tightly to the flat out-

line of a mouthpiece, the medullar surface of the double reed must be transversely curved so that it can be closely attached to the staple or bocal by which it is joined to the instrument. The staple is a slender brass tube, the basal end of which is placed in cork for firm insertion in the instrument. While the single reed consists of a short section of cane, tapered at one end to a thin edge, the double reed consists of a long piece of cane, scored and then folded at the midpoint with epidermal surfaces exposed, and tapered to a thin dimension at the midpoint.

Oboe reeds are manufactured from cane tubes about 15 cm. long and 1 cm. in diameter. The tubes are split into three sections, and these are trimmed along the edges to a uniform width and sawed off at a uniform length. The sections are placed in a machine, and the inner surface is gouged to such a degree that the cane is about .6 mm. thick at the thickest point and tapers uniformly to the edges. In order to close the grain left open by gouging and to smooth the surface, the cane is scraped with a circular blade arranged somewhat like that of the familiar glass cutter.

During the subsequent steps the cane is repeatedly soaked in water to simplify cutting and bending. The cane section is placed on an easel (a rounded, dowel-like support) and transversely scored at the midpoint of the epidermal surface with a sharp knife, just cutting through the hard outer tissue. It is placed over the edge of a knife blade and folded double along the line of the shallow cut. The wet cane is then placed in a shaper. This tool consists of a blade that is broad at the end and tapers somewhat toward the base, where a clamp is set on each of the two surfaces to hold the ends of the cane in place. With the cane folded over the shaper blade and clamped in place, the edges are trimmed

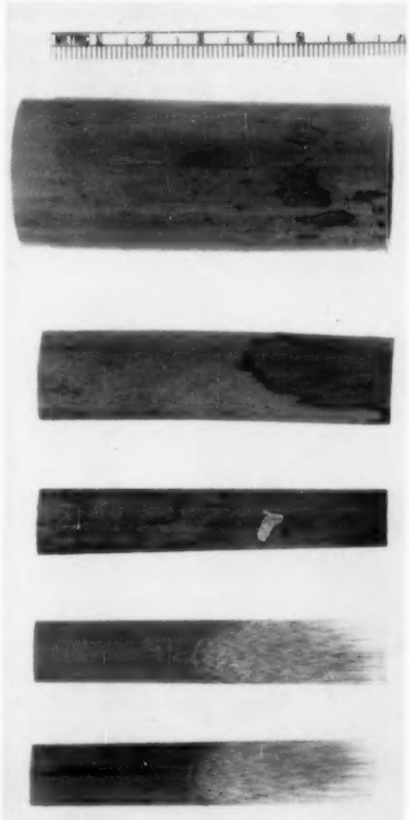


FIG. 12. Stages in the preparation of clarinet reeds. From top to bottom: cane tube; cane quarter section; reed blank, flattened on medular surface; blank with shaped blade; completed reed with rounded tip. (U.S.D.A. Photo, cane courtesy of Arnold Brilhart)

to conform to the outline of the blade. The shaped cane is straightened and placed on the easel, and the two ends are beveled on the epidermal edge with a file. The cane, still wet, is folded again and the edges are smoothed with fine sand paper.

A tubular staple is inserted between the free ends of the folded cane to a distance of about $\frac{1}{4}$ inch, and the ends

are firmly clamped in place with fine wire in such a manner that the edges of the reed come together completely. At a point just beyond the end of the staple the reed is wound tightly with fine silk thread. The wire is then removed and the winding completed down to the cork.

After the cane is dry the face or lay of the reed is prepared. By drawing the plaque inserted between the tips of the two elements, the lay is scraped until the corner of the triangle most distant from the tip has been rounded. The tip is then scraped very thin, and minute adjustments are made to adapt the reed to the requirements of the individual musician and his instrument.

The base of the reed is wrapped with

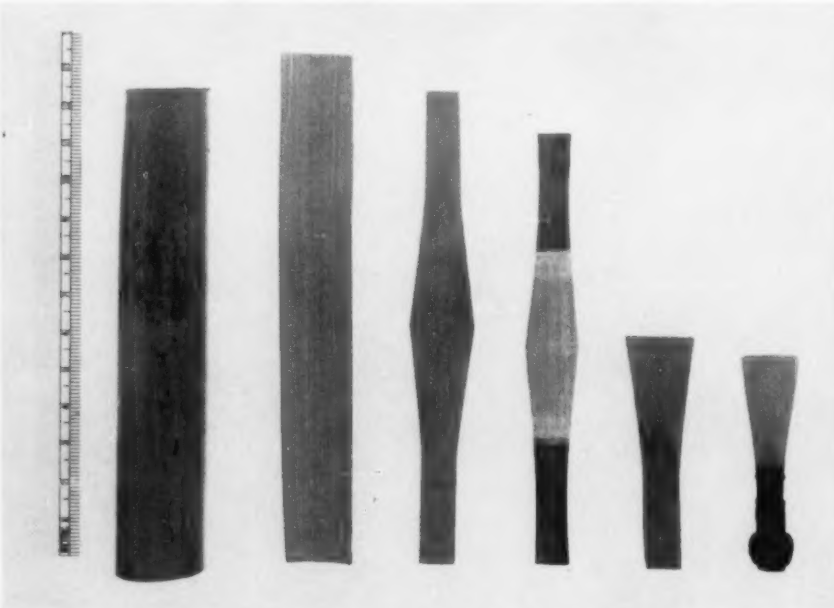


FIG. 13. Stages in the preparation of bassoon reeds. From left to right: cane tube, trimmed and gouged cane section, gouged surface showing; shaped gouged-cane; shaped gouged-cane with blade partly cut; folded cane with blade partly cut; completed reed. (U.S.D.A. Photo, cane courtesy of Jack Spratt)

end of the double reed over a file, first one edge and then the other, the two edges are beveled to form a gently inclined face of triangular shape. The two terminal edges are filed until only a few unsevered fibers hold the two reed elements together. The tip of the reed is placed upon a block, and a minute portion is cut off square, separating the two cane elements. With a thin oval

a small wet sheet of filmy material that shrinks when dry. When dry, this wrapping and the silk winding are covered with a special reed cement.

Preparation of reeds for the English horn does not differ significantly from preparation of reeds for the oboe but requires larger cane and certain larger or otherwise different tools.

Double reeds for the bassoon are pre-

pared from cane tubes about 2.8 cm. in diameter. They are split, trimmed, and gouged to a size 2 cm. wide, 12 to 14 cm. long and 1.25 mm. thick at the center, tapering to about .5 mm. along the edges. The gouged cane-section is clamped in a shaper and trimmed to conform to the outline of the shaper. The shaped cane is approximately 1.8 cm. wide at the midpoint and 1 cm. wide at each end. The epidermal surface is scored crosswise with a knife at points 2.5 cm. on each side of the mid-point. With a knife and finally a file, the cane is tapered down from each score to the mid-point until the latter is about .25 mm. thick. The edges of the cane that will form the basal part of the finished reed and that will finally surround the tubular staple or bocal are beveled with a file to an angle of about 45°. With the cane laid on a block, the remaining epidermal surfaces are scored lengthwise with a knife along the two portions that will form the basal part of the finished reed. These scores are cut very lightly, just through the hard surface, about 1 mm. apart. The cane is folded at the mid-point and the two ends are doubled together with scored epidermal surfaces on the outside and bound together firmly with several pieces of fine wire. The base of the reed splits evenly along the scores as it is forced on a mandrel, a tapering tubular tool attached to a long handle, used to hold the reed during the final stages of preparation.

The two faces of the reed are tapered down to the tip with a file. The reed is then placed on a block and the tip cut away squarely, separating the two cane elements. A flat plaque is inserted between the tips of the reed, and the faces are scraped with a knife until they vibrate freely when played. The tip and edges just above the tip of the finished reed are very thin, and the middle and the upper surfaces are slightly rounded. At this stage the reed is wrapped and finished more or less in the same manner as described for oboe reeds. The completed reed is removed from the mandrel and attached to the bocal of the instrument.

Production and Prices

Official statistics are not available on the quantity of cane produced or the number of reeds manufactured in either the United States or France. Production of cane in France for the manufacture of reeds is roughly estimated at 200,000 to 300,000 pounds per year, of which 40,000 to 50,000 pounds is shipped to the United States. French manufacturers produce 15,000,000 to 20,000,000 reeds annually and market about one-third of these in North America. Approximately 20,000 pounds of cane are produced in the United States, and American manufacturers produce from 5,000,000 to 7,000,000 reeds each year. The total quantity of reeds sold in the United States amounts to between 10,000,000 to 15,000,000 annually. Probably 95% of these are single reeds for clarinet and saxophone.

American grown cane in large lots is priced at about 40 cents per pound. French and Spanish cane in large lots is valued at $1.10 to $1.95 per pound for top quality and $.85 to $1.25 for unselected cane of assorted thickness. On a retail basis, tubes of selected French cane sell for $5.00 to $8.50 per pound. Mexican cane is currently quoted at $2.00 per pound.

Single reeds for clarinet and saxophone sell for 20 to 60 cents apiece; single reeds for bagpipe drones are about 25 cents each. Finished oboe reeds are valued at $1.30 to $1.75, and finished bassoon reeds at $1.50 to $3.50. Double reeds for bagpipe chanter cost 50 to 75 cents.

Quality of Cane and Reeds

Prior to World War II, when the cane shortage was extremely acute and mu-

sicians were forced to turn to any available source, it was generally accepted that high-quality cane could be obtained only from a special strain of *Arundo donax* and that only the environment of southern France could produce good cane. Today there is no doubt but that each of these precepts is a fallacy; however, a great majority of musicians still insist that French cane is far superior to any other. As pointed out previously in this paper, cane from many geographic sources has been successfully used for the production of reeds. Several writers have reported that Spanish, Mexican, and American canes when distributed as "French" have been judged to be of finest quality by outstanding musicians. When the same lots of cane were correctly labeled as to origin, they were considered to be very inferior.

Musicians and manufacturers are fairly well agreed that it is difficult to distinguish good from bad cane by visual examination unless there are obvious flaws. Although the characteristics of quality cane are intangible, many criteria have come to be widely accepted.

Cane of a rich golden yellow color with a shiny surface is preferred; cane of a greenish tinge was either too young when cut or was not properly cured and is likely to be too soft. Cane with a flat, dull, dirty color is also unsatisfactory. Such discoloration apparently results from unfavorable conditions during the early stages of curing or from a fungus disease of the plant. The grain must be fine, straight and regular with tiny but prominent, even, parallel ribs. Material suitable for making reeds is considered to be more dense than ordinary cane. Cane that is soft with loose fibers or overly porous is unsatisfactory.

In the finished reed, the veins should extend to the tip. The reed should produce a good tone and vibrate correctly at all pitches of the instrument. For quick response, it must be flexible and highly resilient.

A favorite test is to wet a reed or piece of cane and blow hard through one end. If bubbles develop at the opposite end the material is regarded as being too porous.

One correspondent has found, in a quest for a material suitable for use in scientific instruments, that French cane used in woodwind reeds has a density of .4 while American cane has a density of .5. From criteria established by musicians just the opposite would be expected.

The application of scientific methods to the testing of cane quality has been very limited. The usefulness of data gained by such an approach is limited to some degree by the varying preferences of individual musicians. One study of hardness, stiffness, and elasticity of cane indicates that the most satisfactory reeds are made from soft canes that show the least stiffness and the greatest amount of recovery after bending. The degree of recovery after bending was considered to be one of the most important characteristics associated with tone quality and response of the finished reed (31).

Possibility of Cane Production in the United States

The experience of American musicians during World War II with cane of American origin establishes without question that good-quality cane can be grown in this country. Much must be learned, however, before a consistently good product can be marketed, and it is questionable whether such an American product can compete cost-wise with French cane under present conditions. As pointed out earlier in this paper, even in France only a small proportion of the yield is considered satisfactory for making reeds. A significant portion of the French growers' income is obtained from

the sale of lower grade supplies for use in making baskets, fish poles, and other products. The United States does not have outlets to absorb cane that is below reed grade, but such a market might be developed.

The only possibility that can be foreseen for intensive cultivation of *Arundo donax* in the United States is as a source of industrial cellulose. Under present conditions, this possibility must be considered as remote. Should cane be cultivated for this purpose, economic factors probably would restrict its growth to the more humid areas where the highest yields could be obtained. It is doubtful that cane produced in such areas would be suitable for reeds.

Any American cane made available at a price and quality competitive with the French product will still have a great psychological disadvantage. A majority of musicians are thoroughly convinced that only cane from France is suitable for their use. This belief can be attributed to the many dismal failures of non-French cane as well as to the good reputation that French cane has long enjoyed.

A careful study of atmospheric and soil conditions under which cane is produced in southeastern France should point the way to the selection of the most satisfactory American environment. Such an environment appears most likely to be found in the southwestern or western United States. Careful study of the botanical and agronomic characteristics of the plant, in connection with detailed study of the physical and musical quality of cane, would provide a firm basis on which attempts to establish the industry could be made. It is questionable whether the industry could profitably support the expense of the necessary research.

Cane Substitutes

In times of acute shortages musicians have attempted to form reeds from a wide variety of materials including boxwood, ebony, heather root, lancewood, teakwood, celluloid, hard rubber, synthetic resins, ivory, and silver. All of these materials proved unsatisfactory.

During World War II, a musician made reeds from bamboos, *Phyllostachys bambusoides* and *Semiarundinaria fastuosa*. These materials were much too hard and entirely undesirable.

Elder stems and goose quills were formerly employed very extensively to make drone reeds for bagpipes. The requirements of these reeds are less rigid than those of other types.

During World War II, the U. S. Department of Agriculture experimented with several substances in an effort to develop a tasteless water-proofing material for cane reeds. It was found that ethyl cellulose, a tasteless chemical, could be used for this purpose. Reports were received that treated reeds were very satisfactory, but this method has not been accepted by the most critical musicians.

During recent years much experience has been gained in the manufacture of plastic reeds and they are currently in wide use in high school and college bands. Plastic reeds have not gained the acceptance of professional musicians who complain of poor tone and the slippery nature of these reeds resulting from their lack of porosity. If these problems can be overcome, plastic may in time completely replace cane, for manufacture of reeds from plastic can be much more easily controlled. Plastic reeds are now available for clarinet, saxophone, and bassoon.

Utilization: Industrial Cellulose

The high production of vegetative material by *Arundo donax* has long attracted the attention of those interested in the production of paper. As early as 1830 samples of paper were made from

TABLE 1

FIBER DIMENSIONS OF *Arundo Donax* CULMS (MM.)

Source	Length	Average Length	Width	Average Width
Imperial Institute (2)	0.25–4.57	1.52		
Raitt (32)	0.62–2.25	1.50	0.012–0.037	0.017
Onofry (27)	0.6 –5.4		0.020–0.025	
Jayme *et al.* (17)	0.1 –5.0			
Bhat & Virmani (8)	0.80–2.80	1.45		

this plant by boiling stem material that had received a prolonged treatment in calcium hydroxide. Increased interest in this plant has been expressed periodically during the present century in nations where supplies of pulpwood have become critically low, especially during the years just before and during World War II.

Fiber Dimensions. In fiber length (Table 1), an important index of potential pulp or paper strength, *Arundo* compares favorably with deciduous tree species, the average fiber length of which ranges from approximately 1 to 1.8 mm. It compares less favorably with coniferous species, in most of which the average fiber length is 3.5 to 6.0 mm. The length : diameter ratio of *Arundo* fibers is approximately 75 : 1, compared with a ratio of approximately 100 : 1 for fibers from both deciduous and coniferous trees. Other factors being equal, pulp with a high fiber length : diameter ratio produces stronger, more finely textured papers. In a comparative study of crop residues and native German plants, which included 25 species of non-woody or semi-woody plants, Jayme *et al.* (17) reported that *Arundo donax* fibers are of greater length than those of any other species examined except hemp.

Onofry (27) separated a stem into five sections and measured fiber lengths in each separately. In each sample, approximately 70% of the fibers measured fell within the range of 1.2 to 2.0 mm.

A test of cane sulfate-pulp on a screen classifier indicated that about 50% of the fiber is retained on a 28-mesh screen and 35% on a 100-mesh screen, and that 15% passes through the latter (14).

Chemical Composition. A summary of chemical analyses of *Arundo donax* culms is given in Table 2. While it is difficult to compare data of this type because of the varying methods of analysis, these figures collectively give a good

TABLE 2

CHEMICAL COMPOSITION OF *Arundo Donax* CULMS *

Source	Cellulose %	Pentosans %	Lignin %	Ash %	Alcohol-benzene solubility %
Raitt (32)	42.8	33.6†	9.4	7.4	
Tomeo *et al.* (39)	40.1– 44.4	22.7– 27.5	23.4– 24.4	3.8– 4.8	10.7– 11.9
Jayme *et al.* (17)		24.3	16.4	2.9	
Bhat & Virmani (8)	58.0	18.4	22.0	3.6	6.8
Kocevar & Javornik-Kosler (18)	43.8 (alpha)	20.8	22.4	2.5	

* All figures on oven dry basis.
† Includes pectose, fat, and wax.

indication of the chemical nature of the plant.

The higher cellulose analysis (58%) cited from Bhat and Virmani (8) can be attributed to their use of the Cross and Bevan method for this determination. Cross and Bevan cellulose contains a considerable proportion of hemicellulose and is here reflected in the lower content of pentosans. On the basis of Cross and Bevan cellulose content, *Arundo donax* compares favorably with wood (50–60%)[2] and bamboo (57–66%) and is somewhat better than most of the grain straws (45–52%). In the previously mentioned study by Jayme *et al.* (17), bleached *Arundo donax* pulp had a higher alpha cellulose content (89.3%) than any other pulp tested.

Arundo donax contains considerably less lignin than woods (25–30%), somewhat more than grain straws (12–19%), and in this respect compares favorably with most bamboos (14–32%). Lignin is the principal constituent that must be removed to produce a fine pulp, and, as a rule, plants with low lignin content can be expected to pulp easily.

In pentosan content donax cane does not differ greatly from bamboo (15–21%), grain straws (25–30%), or hardwoods (20–25%) but contains considerably more than soft woods (8–14%). Like the other grasses donax cane has a high ash content (grain straws 5–10%, bamboo 1–3%), considerably higher than wood (usually under 1%). The silica content of the culm ranges from 1 to 2%.

Experimental Digestion for Pulps. Table 3 presents selected experimental data summarizing the currently available research on the soda, sulfate, and bisulfite digestion processes for the production of paper pulp from *Arundo donax*. The digestions represented in the table were in most cases selected from two or more parallel treatments as illustrating the most suitable procedures for producing the highest yields of pulps that possessed satisfactory strength qualities and that could be bleached to a satisfactory degree of whiteness with an economical amount of bleaching powder. Crushing of the material and chipping it into small fragments before processing speed up penetration of the cooking liquor into the stems (8). Penetration is hampered by the low permeability of the outer layers of the stem due to their high density and the presence of a considerable amount of wax.

The leaves make up as much as 45% of the total dry weight of the raw material but contribute little to the pulp produced (8). Leaves digested under conditions similar to those indicated for digestions 3 and 4 yielded only 29% unbleached pulp and required slightly more alkali than was required for digestion of culms or mixtures of culms and leaves. Bleaching of the leaf pulp required twice as much chemical as was required for bleaching of the culm pulp. This refinement caused a 50% reduction in weight of the leaf pulp in contrast to a 14% reduction in weight of the culm pulp.

Di Felippo (11) reported that laboratory tests with leaves produced a bleached pulp yield of only 26.1%. The breaking length of this sample (the length of a strip of paper required to cause the strip to break under its own weight) was 2,800 m. Under comparable conditions, cane accompanied by sheaths and leaves gave a bleached pulp yield of 34.0 to 35.5% with a breaking length of 6,250 to 7,000 m. Canes without leaves or sheaths yielded 40.7 to 45% bleached pulps with breaking lengths of 6,300 to 6,800 m. Leaves produce pulp of poor strength but do not effect strength properties appreciably when pulped with culms. In addition to producing lower yields of pulp and re-

[2] Percentages cited for wood, bamboo, and grain straws are approximate.

ducing, capacity-wise, the efficiency of the digester, leaves increase the amount of material soluble in alkali which increases the consumption of chemical and contributes to the formation of pulps with a jelly-like consistency. Washing of such pulps is difficult. The combination of leaves with stems also leads to lack of uniformity in the degree of cooking unless expensive, more drastic treatments are used.

Item **8** in Table **3** provides the essential details of a pilot-plant scale digestion of *Arundo donax* with an equal quantity of *Phragmites karka*. The latter is an Indian grass, similar in appearance and habitat to *Arundo donax*, and frequently confused with it in the field (**9**). The digestion produced a clean well-cooked pulp in an amount comparable to yields obtained when *Arundo donax* was cooked alone. This pulp was formed into a sheet on a machine operated at a speed of **50** feet per minute, producing a writing paper with satisfactory strength properties. Tests of this paper (machine direction) indicated a breaking length of **2680** m. and a tear factor of 41.1. The burst factor was 17.1. Since the pulp from these two grasses is short fibered, addition of a quantity of long-fibered pulp

TABLE 3

EXPERIMENTAL DIGESTION OF *Arundo Donax* FOR PAPER PULP

Source	Process	Total chemical (as Na_2O) (%)	Time (hours)	Temperature (°C.)	Yield unbleached pulp (%)	Remarks
1. Raitt (32)	Soda	16.3	6	153	37.0	Starches previously extracted.
2. Dupont & Escourrou (12)	Soda	21.1	3	160	42.5	Raw material contained 8.1% moisture.
3. Bhat & Virmani (8)	Sulfate	13.2	6	153–162	42.6	Without leaves. Yielded 36.3% bleached pulp...
4. Bhat & Virmani (8)	Sulfate	13.2	6	153–162	35.0	With leaves. Yielded 30% bleached pulp.
5. Bhat & Virmani (8)	Soda	14.0	6	153–162	45.0	Without leaves. Yielded 38.3% bleached pulp.
6. Bhat & Virmani (8)	Soda	14.0	6	153–162	35.0	With leaves. Yielded 27.1% bleached pulp.
7. Tomeo, Herrero, & Astor (37)	Sulfate	17.5	5	170	42.0	
8. Bhat & Virmani (9)	Sulfate	17.1	6	153–162	43.3	Mixed with equal quantity of *Phragmites karka*. Yielded 34.5% bleached pulp.
9. Dupont & Escourrou (12)	Bisulfite SO_2 (Free SO_2) Na_2O	(gm./l.) 65.6 (56) 9.3	12	123	45.3	Raw material contained 8.6% moisture, extracted with H_2O, 1 hr. at 100° C.

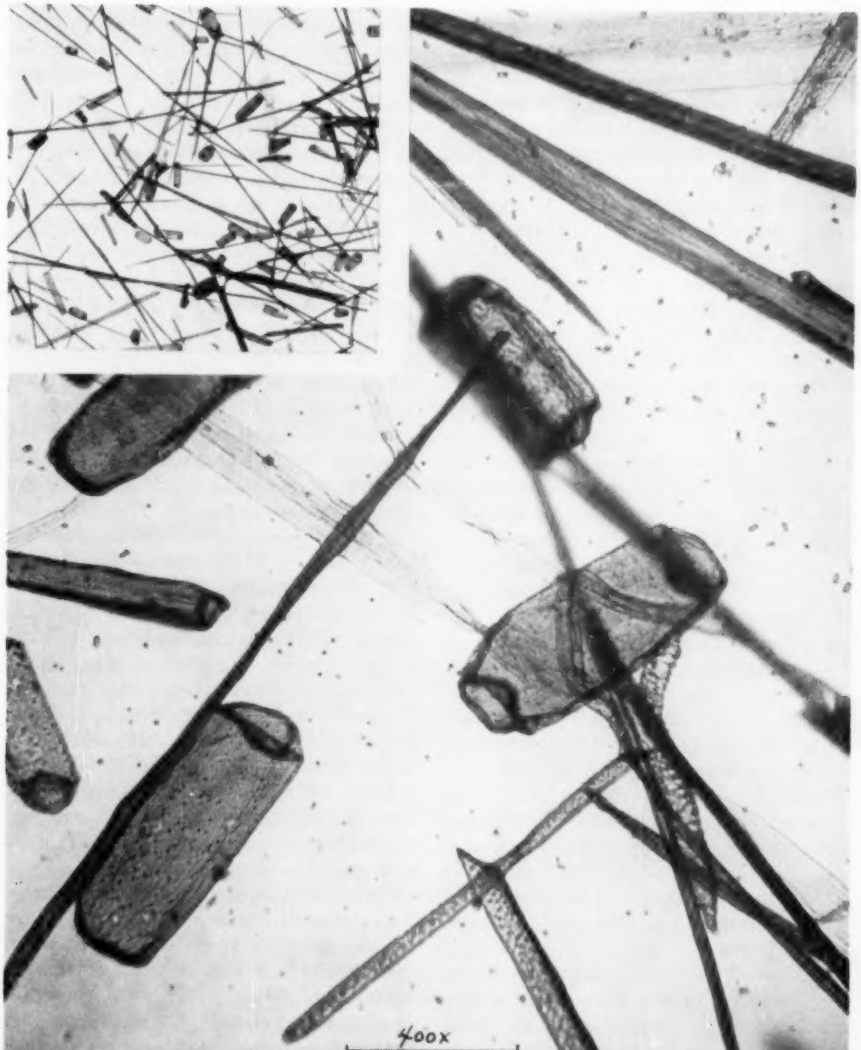


FIG. 14. Macerated *Arundo donax* culm, sample from internode, 400×. (Insert 50×). (U.S.D.A. Photo, courtesy of Northern Utilization Research and Development Division, Agricultural Research Service).

would be necessary before it could be used on a high speed commercial machine.

Large-scale tests have been made in the United States by Gaylord Container Corporation on 1000 tons of cane obtained from wild stands along the Rio Grande (14). Cane cooked by the sulfate process with 7.5 to 13.5% active alkali for 2.5 to 3 hours gave pulp yields of 35.6 to 52.4%. The pulps were very weak. In comparison with a refined pulp from pine having a bursting strength of 61.4, tear strength of 93, and tensile strength of 19, pulps from *Arundo donax* that were refined to the same freeness had bursting strengths of 32 and 37, tear strengths of 57 and 48, and tensile strengths of 12 and 16. A satisfactory corrugating sheet was produced, but it was not comparable in strength with the sheets regularly produced by the mill. Mixtures of cane and pine pulps showed a decrease in strength more or less in direct proportion to the quantity of cane pulp used.

In the mill-scale tests just discussed, mixtures of cane and Kraft pulps were used to produce papers of several types. All were of poor strength and had smoother formation and higher dirt count than Kraft papers and were slower draining on the wire. The papers from the mixed pulps were easier drying. It was concluded that cane is not satisfactory if strength is important, but it may serve for the production of special papers.

A number of mill-operating problems were evident during processing of the cane. The large quantity of dust created by shattering of the cane resulted in unpleasant working conditions. Digesters did not blow clean, and washing of the pulp was difficult. Among other unfavorable factors, the high silica content of the cane caused serious scaling of equipment and created difficulties in liquor recovery.

The entire culm of *Arudo donax* breaks up comparatively easily, unlike culms of many bamboos and other grasses in which the nodes resist disintegration. The pulps are easily and economically bleached. In comparison with pulp from coniferous wood, they are of but medium strength because of their comparatively short fibers. However, they are satisfactory for the production of writing and printing papers, and their strength can be increased considerably by the addition of 10% of long-fibered coniferous pulp. Strength properties of standard sheets formed of bleached pulps obtained in digestions 3, 4, 5, and 6 of Table 3 were: breaking length 9,348 m., 9,650 m., 9,325 m., 9,017 m.; tear factor 116, 113, 114, 90; burst factor 57, 53, 54, 54. Raitt (32), taking into consideration all aspects of the utilization of grasses for paper pulp, considered donax cane to be one of the outstanding Indian grasses that might be used for this purpose. This grass could be pulped separately or in mixture with any of six other outstanding Indian species. Like pulps from other non-woody plants, *Arundo donax* pulps have a content of foreign matter that is considerably higher than wood pulp.

Pulps with high alpha-cellulose content are desirable for the production of special papers including those where permanency is a major requirement. They are also used as dissolving pulps for the manufacture of rayons, cellophane, cellulose-acetate, cellulose-nitrate, and other cellulose derivatives. A great portion of high-alpha pulp is utilized in the production of rayon. A pulp to be used for this purpose must have an alpha cellulose content greater than 92%, a pentosan content less than 2.5%, an ash content less than 0.11% and must be lignin-free. The pulp must also have suitable physical characteristics. For the production of cellulose acetate and other cellulose derivatives, the chemical

requirements are more rigid than for pulps to be used for rayon.

Acid hydrolysis of raw cane, prior to digestion, favors the production of pulps with a high alpha-cellulose content (12, 18, 37, 38). The content of pentosans is reduced and there is a parallel reduction in the pentosan content of the final pulp. The most complete data on the acid hydrolysis of *Arundo donax* culms are those given by Kocevar and Javornik-Kosler (18) for experimental treatments of material described in Table 2. Prehydrolysis of this culm material with .5% and 1.0% H_2SO_4 at 135° C. for 3 hours yielded extracted culms in quantities of 77% and 65%, respectively, with pentosan contents of 8.6% and 7.0%. These two extracted samples, when digested by the sulfate process ($NaOH$, Na_2S, Na_2CO_3) with 3% total alkali (as Na) for 5.5 hours at a maximum temperature of 170° C., furnished crude pulps in yields of 34% and 29%. The two crude pulps analysed as follows: alpha cellulose 87.0%, 90.6%; lignin 4.6%, 3.1%; pentosans 6.4% 4.8%; ash .44%, .29%. When refined by bleaching, alkali extraction and a second bleaching, the pulps contained: alpha cellulose 95.0%, 96.3%; pentosans 3.6%, 2.9%; ash .13%, .11%. The refined pulps were lignin-free and were produced in yields equivalent to 25% and 22% of the weight of the original material.

In contrast to the two trials cited above, less drastic acid hydrolysis of raw culms with .1% H_2SO_4 for six hours at 135° C. decreased pentosans only slightly, from 20.8% to 20.4%. With digestion and refinement conditions parallel to those cited, this trial yielded 29% of refined lignin-free pulp with 88.5% alpha cellulose, 6.6% pentosans, and .14% ash. Closely comparable results were obtained by Tomeo *et al.* (37, 38) employing 1% H_2SO_4 at 120° C. for 30 minutes.

Experimental hydrolysis of raw cane with nitric acid is reported by Dupont and Escourrou (12). Their data include so many variables that generalizations are difficult. A sample previously extracted with boiling water to give a 10% dry extract, when treated with 3.7% HNO_3 at 100° C. for 2 hours yielded 18.5% of dry extract containing 14% reducing sugar. Digestion of the extracted material with 9% NaOH at 100° C. for 1 hour yielded 43.4% of crude pulp. Hydrolysis of a sample with 2.4% HNO_3 at 100° C. for 3 hours yielded 49% dry extract containing 27% reducing sugars. Digestion of this extracted residue with 12.9% NaOH at 115° C. for 2 hours yielded 41.4% of crude pulp. The crude pulp contained 81% alpha cellulose. By bleaching, the alpha cellulose content was increased to 85.2%. Fermentable sugars can be recovered from these acid treatments. Such sugars obtained as a by-product of the wood pulp industry in Europe are important in the production of alcohol and during World II were used to grow a yeast which supplied a protein supplement for the German army.

Industrial Utilization. Although considerable attention has been given to the potential utilization of *Arundo donax* for paper and dissolving pulps, only in one instance has this plant been used on a large-scale industrial basis. Prior to World War II, the Italian government encouraged the development of new sources of rayon pulp (4, 24, 26). This interest was stimulated primarily by the desire of the dictatorship to be independent of foreign sources of textile fibers and the desire for an export product. It was recognized that an immediate source of raw material was needed, that the designs of the dictatorship could not wait 20 to 30 years for the establishment of coniferous or deciduous tree plantations. Recognizing that annual crop residues could not be utilized, because of technical and eco-

nomic problems, attention was directed to the development of a new crop as a source of industrial cellulose. Snia Viscosa, a large textile corporation, conducted a program of research on all materials that offered any potential for this purpose. As a result of this effort, *Arundo donax* was selected as the preferred species, because of its large yield, ease of preservation, and high content of top-quality cellulose.

Although later developments indicate that *Arundo donax* was not an economical source of pulp, the new venture was initiated with great enthusiasm. Plans were drawn up for the construction of a factory to use *Arundo donax* and for an accompanying plantation to supply the necessary raw material. Favored by the personal encouragement of the dictator Mussolini, work on this agricultural-industrial complex was initiated in 1937. A factory, town, and farm were established at a site later to be known as Torviscosa in the vicinity of Udine, Venezia Province, in northeastern Italy. The farm, established on land reclaimed from a marshy, previously uncultivated waste, originally covered 6,000 acres. By 1941, donax cane had been established on 7,500 acres, and plans called for a final holding of 15,000 acres to be in full production by 1943.

The establishment of new plantings and their maintenance apparently followed the methods developed by Onofry (27). This system consisted of dividing the fields into strips 2 m. wide, alternating with strips about 1.3 m. in width, each bordered by a drainage ditch .3 m. wide and .3 m. deep. Rhizomes were planted in east-west rows along the northern borders of the wide strips and were permitted to expand toward the south. In fields established on hillsides planting was arranged so that expansion would occur up-slope.

By the fourth year, the initially planted strips were densely covered with cane growth. Since the original rhizomes had become exhausted, cane production in the area initially planted had greatly diminished, and it was necessary to remove the dead growth.

In the following years, the young rhizomes were allowed to expand toward the south into fresh soil, and the exhausted rhizomes were removed from the opposite border of the strip. By the eighth year the cane shifted completely on to the strip that was originally bare.

This method of maintaining the fields allowed the cane to occupy only half the area during any one season, and the strips that were free of cane could be planted with legumes to improve the fertility of the soil.

The Onofry system was regarded as the most satisfactory for maintenance of high sustained yields. Production and quality of the cane were increased by greater exposure to the sun, improved drainage, higher soil fertility, and removal of exhausted rhizomes.

According to figures made public by Snia Viscosa, the average annual production at Torviscosa was 35 tons of green cane per acre (24). From this could be obtained 15 tons of dry cleaned cane which served as the raw material for the production of four to five tons of high quality dissolving pulp. This yield of pulp was considerably more than could be obtained from an acre of forest. The ultimate goal was to obtain from this one establishment a production of 65,000 tons of pulp per year, 40% of the total Italian requirement at that time.

In contrast with the yields cited above, natural stands of *Arundo donax* in India are reported to yield 3.2 tons of dry grass per acre yearly on a sustained-yield basis (32). In one area a plot of natural cane yielded five tons of dry grass per acre but this area was not fully stocked; the yield for a fully stocked area was considered to be six

tons per acre. Another sample area yielded a phenomenal 43 tons per acre, but the crop consisted of many persistent bases of old culms and undoubtedly represented the growth of a number of years. In the United States, fairly good wild stands are reported to yield $8\frac{1}{3}$ tons of oven-dry cane per acre; poorer stands yield $5\frac{1}{4}$ tons of oven-dry cane per acre (14).

Italian plantings, established with rhizomes, reached full production after three years and were expected to continue at full efficiency for at least ten years. Afterward, the fields were to be renewed by removal of the old rhizomes and replanted as necessary. The fertility would be restored in part by heavy applications of manure.

The cane was harvested during the winter and allowed to dry for several months in the open. At a later date, the harvest was collected in large piles and covered with cane in such a manner as to shed water. After seasoning for several additional months to assure a degree of uniformity, the raw material was transported to the mill as needed. At the mill, bundles of cane were crushed between rollers and then passed through a chipping machine to cut the culms into fragments about $\frac{3}{4}$ inch long. Seeds, leaf and sheath tissue, and a portion of foreign material were removed by machinery and returned to the farm to be used as bedding for cattle. The cleaned material was stored in large silos from which it passed to the boilers by gravity.

The cleaned chips were conveyed to boilers where the sugars were extracted with water at 100° C. The chips were then conveyed to storage bins above the digesters.

The extracted chips were cooked by the calcium bisulfite process in large stationary digesters to remove lignin and some other non-cellulose substance. The crude pulp was released into pits, washed, and passed to a machine to break up fiber aggregates and separate out the portion that was not sufficiently disintegrated. It was then passed into a separator, where sand and other heavy impurities were allowed to settle out. After washing, the pulp was cooked with mild caustic soda to remove silica and most other non-cellulose substances.

After again being washed, the pulp was subjected to a multi-stage bleaching process to remove the last traces of lignin. It was chlorinated, washed, and extracted with 10% caustic soda. Following an additional washing operation, the pulp was treated with hypochlorite bleach and given a final washing. The refined pulp was formed into sheets on a Fourdrinier-type machine. These sheets containing about 20% moisture were ready for use in the rayon mill.

The yield of refined pulp was claimed to have been 31%. The product was reported to have contained 97% alpha cellulose, 2.4% pentosans, and 0.1% ash.

The fibrous material that was not sufficiently disintegrated following the first cook and separated out before the second cook was used for the manufacture of wrapping paper.

Ethyl alcohol was a valuable byproduct of the industrial process. The hot-water extract obtained from the crushed chips was collected in large storage tanks from which it was drawn into other tanks where the sugar was fermented to alcohol. Distillation of the fermented extract yielded as much as 54 gallons of 95% ethyl alcohol for each ton of pulp produced. The cane was reported to contain 14% sugar (24).

Publicity associated with the opening of the factory and its 1940 expansion, in industrial and technical journals as well as in press notices, indicated that the industrial utilization of *Arundo donax* for rayon pulp by Snia Viscosa was highly successful and apparently economical. At that time, however, certain Italian sources of information indicated

that the efforts to manufacture industrial cellulose from cane were almost a complete failure and that the factory in reality used timber imported from Yugoslavia. It was claimed that the cellulose produced was of inferior quality and was not accepted by rayon manufacturers as long as pulp was available from other sources. According to those reports, the cane pulp was used only by Snia Viscosa and its affiliates.

More recent reports indicate that, while the production of rayon pulp from cane never by any means approached the publicized goal of 65,000 tons per year, a considerable amount of this product was manufactured just prior to and during a part of World War II and probably for several years afterward. Recent reliable estimates indicate that production reached as high as 6,600 tons per year.

During the years immediately following World War II, Snia Viscosa is reported to have used 50% *Arundo* pulp and 50% imported Swedish wood pulp for the production of rayon.

At present, the Snia Viscosa factory at Torviscosa is the only establishment in Italy that utilizes cane for production of rayon pulp. Cane is currently used by this factory for the manufacture of about 4,400 tons of pulp each year. The principal raw material is now birch pulpwood imported from Yugoslavia.

The Torviscosa plantation has reduced the acreage of cane to 5,000 acres. This planting is maintained to serve as a supplementary source of raw material and provides a source of rhizomes for rapid extension of the acreage in the event that foreign supplies of raw material are cut off or become sufficiently expensive to justify the use of *Arundo donax*.

Excluding the effect of war-time conditions, the failure to attain the high goal of production of rayon from cane was due primarily to the high cost of producing and processing the raw material. A second factor that influenced production of this material was the marked decrease in demand for rayon in Italy during the post-war years. Prior to and during World War II the Italian government forced the consumption of rayon textiles and thus strongly prejudiced consumers against the product. Reaction against this policy resulted in decreased demand when United States financial aid made available large supplies of cotton after the war.

Arundo donax has recently been exploited as a source of paper pulp in Argentina. In 1952 a plantation of 5,000 acres was reported to have been established for this purpose at Ramallo. During that season an additional 1,700 acres were to have been planted. Establishment of the plantation followed the methods developed in Italy by Onofry (28). Additional information on this development is not available.

Ambitious plans were formulated in France in 1942 for the development of a domestic industry for the production of paper and dissolving pulp from *Arundo donax* (1). These plans called for the construction of a large factory and the planting of 12,000 acres of cane in southern France. In addition, the industry was expected to utilize cane from natural stands occupying more than 15,000 acres. The factory was to employ the methods used by Snia Viscosa and was expected to achieve a final capacity of 400 tons per day, approximately one third of the French requirement.

This industry did not become established, and with the end of the war the interest in substitute sources of raw material waned as imports of established raw materials became available. Recently, however, interest in this source of cellulose has again been indicated in France because of the shortage of foreign currency, which has resulted in a substantial decline in imports. This newly

aroused interest is so recent, however, that no information is available on what path the industry will take.

Recent interest in cane as a source of pulp has been expressed in Yugoslavia (18). Apparently efforts in this area are still of an experimental nature.

Utilization: Minor Uses

Arundo donax is a very versatile material and has been widely utilized for a variety of purposes (10, 15, 21, 25). In many local areas, the plant has served many of the uses to which the bamboos are applied, within the limitations placed upon it by the smaller diameter of its culms. This species finds many useful applications in the vine and garden areas around the Mediterranean Sea. Many farmers maintain a small cane brake in order to be assured of their requirements, and the canes frequently enter commerce in times of local shortages. A large quantity of split culms are made into lattices for drying fruit and vegetables or woven into containers to be used for shipping these products as well as flowers and other materials. For lattices and basket work, young canes are preferred as they are more supple and easily worked. Canes are also used for garden fences and trellises, and for propping up vines and small trees, and the plants are often grown in hedge rows to serve as windbreaks. Leaves are used for tying up vines and other plants.

In Mexico, the canes are soaked in water and then crushed with a rock and woven into mats. The mats are used to construct chicken pens or to prevent the spillage of grain from box car doors.

In many areas where lumber is unavailable or obtained only at great expense, the culms are used in light construction. They serve well in the building of crude shelters and have limited application in the construction of permanent buildings. Mats formed from split culms are well suited for anchoring wall plaster, and the leaves serve as a satisfactory roof thatch. The canes are reportedly satisfactory for use as reinforcement in concrete. The culms are also utilized in the construction of furniture, particularly in the weaving of chair seats.

The culms are widely used for fishing rods and walking sticks and are reportedly used for pipe stems and in the construction of fish traps. Straight slender canes supplied arrows for the Egyptians, Greeks, and other early peoples. In areas where fuel supplies are limited, exhausted rhizomes are used for this purpose.

Employment of this plant for the control of erosion has received wide approval. It is used to advantage for this purpose along the banks of ditches and canals and in shallow drainage paths. The plant can be established in small torrents by staking large clumps of rhizomes to the ground and protecting them against the full rush of water with a covering of soil and straw or small brush (35). In Argentina the plant is recommended as a reinforcement for the edges of mountain terraces, and in Texas and Australia it is used for stabilizing drifting sands (42).

In Australia, donax cane is reportedly well suited as a source of fodder for livestock but the small, leafy, variegated strain is preferred (35). All livestock, including pigs and poultry, are attracted to it; when a horse or cow gains entrance to a garden in which this plant is growing, it is one of the first plants consumed. In the United States, cane is not considered very palatable to cattle but is grazed when other forage is not available (42). The plant is low in protein but has a comparatively high concentration of phosphorus in the upper portions even when grown on soils with an extremely low content of this mineral. Other investigators report that in Turkestan camels never touch this plant

although they readily graze other coarse plants growing with it (29).

Medicinally the rhizome has been used as a sudorific, a diuretic, and as an antilactant and in the treatment of dropsy (21). Two alkaloids, gramine (donaxine) and donaxarine, have been isolated from the leaves (23, 29, 30). The former, originally isolated from barley, raises the blood pressure of dogs when administered in small doses. Large doses cause a lowering of the blood pressure of dogs.

During World War II, an American concern used small pieces of cane cut from defective woodwind reeds in the manufacture of certain scientific instruments. The combination of light weight and good mechanical strength readily adapted the material to this purpose.

In southern France, during World War II, large quantities of cane were woven into large mats and used to conceal roads and paths from enemy view.

Arundo donax has frequently been grown as an ornamental. The inflorescences have been dyed and used for decoration.

An early English patent covered the manufacture of a textile fiber from *Arundo donax* (15). The process called for splitting the culms into long strips by passing them between heavy rollers. After a treatment in caustic solution, fibers suitable for spinning were separated out by beating the material on wooden blocks. The fibers obtained were about 14 inches long and could be processed in the manner used for hemp.

Possibility of Industrial Utilization in the United States

The utilization of non-arboreous plants in the production of pulp creates many problems that place these materials in a disadvantageous position in relation to wood. Problems are created by their bulk and the necessity for their seasonal harvest resulting in greater expense of handling and storage. Pulping of these materials requires larger quantities of chemicals than does the pulping of wood and necessitates the employment of special methods. As an agricultural crop such plants must compete for space with other plants currently established in farming systems.

Arundo donax from natural stands is reported to be a satisfactory pulp source under conditions prevailing in India. The plant apparently shows promise as a satisfactory cultivated raw material in Argentina. In Italy, however, where considerable experience has been gained in the industrial cultivation of cane, the pulp industry relies on less costly imported pulps or pulpwoods.

Under the limitations of our present knowledge, non-arboreal plants when cultivated as a source of pulp are unable to compete with wood in well forested areas. Even in poorly forested countries, non-woody plants used for this purpose are obtained largely as agricultural residues or from natural growth.

Under present conditions, *A. donax* does not offer very much potential as a cultivated crop for the United States. However, among the non-woody, rapidly growing plants, this species is one of the highest producers of cellulose, and its present status will be altered as conditions of the pulp industry change. Increases in the cost of wood pulp will create a better competitive position for *A. donax* and other non-woody plants. The potential of cane as an industrial plant of the future is sufficiently great that some attention should be devoted now to research on its agronomic problems.

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Proceedings of Economic Botany Conference

Introduction

On Tuesday and Wednesday, August 12 and 13, 1958, a small group of interested scientists met to consider problems of mutual interest in the field of economic botany.

The conference had as its goal a discussion of methods to stimulate greater interest in economic botany, the greater inclusion of economic plants in botanical studies, the methods of financing students and researches, and the need for an organization which would help bring like interests together.

The conferees were invited on the basis of their interest in the field. The members were: Dr. Frank A. Gilbert, Battelle Memorial Institute; Dr. Charles Heiser, Indiana University; Dr. W. H. Hodge, Longwood Gardens; Dr. Quentin Jones, U.S.D.A.; Dr. L. J. King, Boyce Thompson Institute; Dr. R. D. Lewis, Texas Agricultural Experiment Station; Dr. Elizabeth McClintock, California Academy of Sciences; Dr. L. G. Nickell, Chas. Pfizer and Co., Inc.; Dr. Charles M. Rick, University of California; Dr. Richard Evans Schultes, Harvard University; Dr. G. Ledyard Stebbins, University of California; Dr. Charles Todd, DuPont Experiment Station; Dr. L. O. Williams, U.S.D.A.; and staff members of the New York Botanical Garden including Dr. W. C. Steere, Dr. David D. Keck, Dr. Bassett Maguire, Dr. Arthur Cronquist, Dr. Clark Rogerson, Dr. E. H. Fulling, and Dr. David J. Rogers.

The conference was opened by Dr. W. C. Steere, Director of the New York Botanical Garden. He pointed out the value of the study of plants of economic significance, the importance of basic botanical studies for the national welfare, and the role of the New York Botanical Garden in endeavors related to economic botany.

There were no prepared papers for the conference although conferees were asked to consider in advance of the meeting certain aspects which were of major interest. Topics for discussion were: aspects of economic botany from the standpoint of industry, of agriculture, of teaching, and of botanical gardens; curriculum requirements for students in economic botany; methods of increasing researches in economic botany; and financing for studies.

The method of presentation of the results of the conference was considered, and the form finally agreed upon is that of a summary of each conferee's contributions. The conference was tape-recorded and typescripts of the tape were circulated to conference members. The summaries appear below under each conferee's name. The editor takes responsibility for the success or failure of this method to record the actual meanings and value of the conference.

The conference was made possible by a generous gift from Mr. Clarence McK. Lewis,* a member of the Executive Board of the New York Botanical Garden.

DR. FRANK A. GILBERT

Battelle Memorial Institute

All botanical research at an industrial research institute is applied or, in other words, economic botany. A considerable portion is chemurgic and is concerned with the upgrading of a crop or plant product, or with uses for this product.

* Mr. Lewis died on January 3, 1959.

Much but not all of this research is published because the results are the property of the company sponsoring the research and not of the institute. The sponsor may or may not choose to keep the results confidential. Interesting subjects for additional research that develop in the course of a project are pursued only if the company concerned wishes to sponsor them.

One advantage that an industrial research institute has is the ability to work on a problem with many facets in several fields. No botanist, no matter how broad his field, could handle such a problem alone, but he is an important cog in an entire wheel.

A disadvantage is the unevenness in the amount of work in any one phase of botanical research. This requires constant reshuffling of personnel with occasional temporary work on certain projects which may not be in one's main field of endeavor. Certain pieces of equipment are not used to full advantage at all times but have to be kept in readiness in case a new project requiring their use is started.

The importance of the flowering plants in economic botany has been emphasized, and with due justice, but in recent years the economic value of the cryptogams has been increasing rapidly in importance both in the drug field and in industrial processes.

To be an authority in this field, the economic botanist from now on will have to have an increasing knowledge of mycology and microbiology.

In some universities, economic botany is given as a filler or cultural course and is often taught by an instructor not trained in economic botany. The course is frequently taken by students in other fields who require a few hours in the biological sciences.

Perhaps the university, in the school of pharmacy, offers a course in economic botany featuring drug plants. This course is taught by a pharmacist. Some courses offered by the departments of geography and economics are actually economic botany. It would seem to be advantageous for several departments to have their students take economic botany taught by a botanist rather than to offer a variety of courses with nearly the same subject matter, one to a department.

Many of the smaller colleges do not offer a major in botany but rather in biology, and where the department is very small the stress is on zoology, sometimes with botany offered by a zoologist. The fact that practically all colleges have pre-medical and pre-dental curricula may be the reason for the zoological trend.

DR. CHARLES B. HEISER, JR.

Department of Botany, Indiana University

I like the term economic botany because it has "botany" in it. I am somewhat concerned because any time something becomes useful, it is taken away from botany. Several fields have been mentioned—agronomy, horticulture, plant breeding, forestry, plant pathology, bacteriology—actually the people in these fields are botanists.

In regard to the mention of plant inventories, I should like to point out that taxonomic monographs and floras are perhaps some of the most important plant inventories. I certainly feel that the economic plants should be included in such treatments. If a new plant becomes important, a monograph of the genus to which it belongs will be of great value to the plant breeder, the agronomist, and so on. We can't overlook the wild plants either, for in order to understand cultivated plants, we have to know something about their wild relatives.

We have been discussing the possibility of bringing new plants into cultivation. At the same time, I think we should be concerned about losing some of our old cultivated plants. Many In-

dians in the United States, I understand, now find it easier to get their seeds from stores instead of maintaining their old strains. To meet such a need as this a seed bank of Indian strains of corn has been established to preserve as many Indian varieties as possible, but there are other cultivated plants which are disappearing. We can never know when some of these might provide valuable genes for a new breeding program, and relatively unimportant cultivated plants today could be major ones tomorrow.

One of the topics given to me for discussion was that of increasing interest in economic botany. This problem is closely related to increasing interest in botany in general. I think part of the problem would be solved if we had greater employment opportunities for botanists. There is no particular difficulty at the Ph.D. level, but the employment opportunities at the A.B. level certainly are not numerous. I was interested to learn from Dr. Rick that at the University of California at Davis there are not enough students to fill the jobs available. This, I think, reflects in part the difference between the agricultural school and the liberal arts college. True, presidents of large industries are stating that they want people with broad training in the liberal arts, but unfortunately their placement bureaus are either not aware of this or they ignore it, for they turn to the school of business and colleges of agriculture instead of to the college of arts and sciences. Dr. Nickell states that industry will be glad to take the good college graduates in botany, but here we are competing with them for we encourage the best students to go in for the Ph.D.

There are, of course, many other things that can be done to stimulate interest in botany. One which I should like to mention relates to the position of botany in high schools. Most high school students are exposed to a course in biology, but it is my impression that they don't gain much of an idea of what botany is about from the courses now being offered. This can perhaps be traced largely to the teacher who may have had little or no botany in college. I feel that the NSF summer institutes for teachers are doing a fine job, but we need still more work at the high school level if we are to get good botanists and create an interest in our field.

From my own experience with economic botany courses, I think that they can do a great deal to encourage interest. I have no idea as to how many such courses are offered in the colleges of this country. It might be interesting to have information on this point. More such courses might help, but it is difficult to add courses to already overcrowded curricula, and then too, we want our students to have more mathematics, more languages and so on. I think it would be a good thing for all botanists to have information on economic botany, but I'm beginning to wonder how we can accomplish it.

What is the best training for the economic botanist? I think there is probably agreement that to be a good economic botanist one needs work in practically all areas of botany. I myself feel that we should not attempt to turn out people labeled economic botanists. Rather we should continue to turn out taxonomists, physiologists and so on. Some of these later on may well become primarily economic botanists.

I think Dr. Hodge made a very significant comment yesterday when he pointed out that it was possible to find groups of plants for study that would include some cultigens. It may well be that some of the problems in the cultivated plants are too involved to turn over to a student for a Ph.D. problem, but this is certainly not true of all groups. We have found some of the genera which include orna-

mentals particularly rewarding as student problems.

I would also like to ask here if it is not true that the botanist, particularly taxonomists, have more or less shunned cultivated plants and weeds. If this is true, I would like to know why. Could it be that these plants are more "difficult" than wild ones? Certainly when man begins cultivating a plant, when artificial selection replaces natural selection, we frequently have problems quite different from those in a group of plants that is strictly wild.

The final problem which was assigned to me for discussion relates to matters of financing. We need money for students, and if we have the money, how are we going to get good students. We also have the problem of finding money for the mature investigators—in particular for those who are engaged on more or less pure research with economic plants.

We have a number of agencies granting money for research—National Science Foundation, Rockefeller, Guggenheim, etc.—but I would like to ask, in particular, if we have tapped industry to the extent we should for the support of our students and our research.

My first impression on a new organization of economic botanists is that since we already have so many societies, why start another one? Everything considered, however, I can see much merit in an organization of economic botanists. I suggest that after we have completed the preliminary steps for such an organization, we consider affiliating with the A.I.B.S. We would not necessarily have to meet with the biologists every year, but I think there would be advantages to being a part of the A.I.B.S.

DR. W. H. HODGE

Longwood Gardens

My interest in economic botany was first generated in the very excellent notes on economic plants included in the outstanding year's course in systematic botany of the higher plants given by Ray Ethan Torrey at the University of Massachusetts. This was supplemented indirectly by contacts with friends enrolled in the course in economic botany offered by Oakes Ames at Harvard University. I later taught economic botany at the university level for several years. Then I moved to the Plant Introduction Unit of the U.S.D.A. at Beltsville, Maryland, where work in economic botany was my chief concern. At present I am associated with Longwood Gardens, famed for its living plant displays. Among its newer displays are a number of examples of economic plants.

I would agree that it is better not to limit economic botany by definition. This discipline covers the whole landscape of botany wherever there exist economic applications. Such better-known facets of economic botany as horticulture and agronomy are well looked after because of their obvious value to agriculture, but certain other essential phases are not, usually for lack of proper funds.

A few comments are perhaps in order first on economic botany and its relationship to the botanical garden. Botanical gardens began as places to grow plants, mostly economic plants. These first gardens were usually medicinal collections started by apothecaries or early physicians interested in plants of use in medicine. Such gardens expanded down through the years to evolve into those like the New York Botanical Garden with its fine collection of living plants which are, for the most part, labeled and hence readily available for study. The pioneer botanical discipline, taxonomy, developed hand in hand with the early botanical gardens. To assist with the naming of plants and to provide permanent voucher specimens, herbaria were also established as part of the functions of botanic gardens. As the years went

by, other botanical disciplines developed in botanic gardens until today the work in a large institution like the New York Botanical Garden represents a cross-section of all botanical science.

Besides these functions of botanic gardens is the function of education for the general public. This is done generally through informal actual contact of the public with plants. Also important are the offerings of practical short courses in various phases of horticulture or basic botany. Usually the public's primary interest in plants at a botanic garden are with those which have economic (horticultural) significance, hence the maintenance of a living collection and the associated program of short courses.

Another function of botanic gardens is the introduction of new plant materials for horticulture. In recent years many botanic gardens, because of lack of funds, have been unable to foster the actual plant exploration which is often required for successful plant introduction of new materials. The new program at Longwood Gardens supports this type of endeavor and is of particular significance, for financial assistance is now being given on a sustained basis to explore for and introduce new or little known ornamental plants. Funds transferred to the U.S.D.A. enable it to actually carry out the explorations along with that organization's regular program for the introduction of agriculturally significant plant germ plasm.

Before we can have dynamic work in economic botany, we need some economic botanists; and before both of these can be taken care of, we need botanists. The current lack of interest in botany (as well as in other sciences) as a career is, I feel, due to outmoded methods of teaching this science. The inclusion of more economic botany in elementary courses would be one way to create interest in the general science. Too often we as teachers fail to emphasize the economic importance of plants to man whether that importance be shown by plants in the home, plants in horticulture or agriculture, or plant utilization by industry. A glance at most introductory botany texts shows that relatively few economic plants are treated as examples. Botany teachers seem to shy away from even mention of plants which are of use to man. In more advanced work, it is just as easy for a teacher to assign an economic group for a student's research (in whatever botanical discipline he may be studying) as it is to work on one which is of no significance to mankind. In my own experience I find that the introduction or mention of economic plants means more interest by the student, and this results in more interest in botany as a science.

College botany could become one of the most interesting courses in a college curriculum. Many people come to botanic gardens (we find this to be the case at Longwood Gardens) to take short courses in botany or horticulture simply because they did not learn the information they desired in their college education. True, some of the people failed to take botany, but wished they had. Often those who took it wish they hadn't, claiming that what they learned had no "carry-over" value to them as home owners and home gardeners. This is unfortunate, for after all, home gardening is one of our biggest avocations today, and we should plan our introductory botany courses as much for the 90% of enrollees who are not going to be botanists but are going to be home owners as for our botany majors. How can professional botanists today expect support for their programs from a public apathetic or uninterested in these problems and especially if their taste for science was soured by a poor introductory course?

Genera with economic species should be suggested to graduate students for

monographic treatment, and wherever possible advanced students should discuss the economic implications in their final work and not pass them by, as is too frequently the case, without one word of comment. There are literally hundreds of groups in this category which are available for taxonomic study. Why they are so frequently ignored in favor of strictly non-useful groups I cannot understand.

Of interest along these lines are the large living germ plasm collections of economic plants maintained directly or in cooperation by the U.S.D.A. in many parts of our country. These collections, of primary interest at present to the practical plant breeder, are of inestimable value to botanical scientists, especially in taxonomy and genetics. Yet, except for the fine collection of tuber-yielding species of *Solanum*, these collections of economic plants (including many genera of agronomic or horticultural import) are practically unused by basic botanical scientists. The U.S.D.A. would give every encouragement to taxonomic botanists. It would do the herbarium botanist a great deal of good to study materials in field collections of this type along with herbarium specimens.

There are other sorts of research problems which would be most helpful to economic botany. Although thorough floristic studies are certainly of great basic importance, I think one of the most necessary practical tasks for economic botany today is a world-wide survey of ethnobotanical uses of plants. As is well known, ethnic uses of many plants are discarded as primitive peoples come into greater contact with modern civilizations. Even though the plants may remain as wild things in nature, the knowledge of their uses in primitive areas will be lost—an unfortunate situation, for this knowledge often serves as a clue to practical modern utilization of aboriginal plants. Rotenone, curare, and reserpine are just three examples of aboriginal plants which have become of tremendous importance in very recent times, even though they have been utilized by primitive peoples for centuries.

Another problem for economic botany is to see that valuable research, which may have been started by government or industry, is brought to sufficient completion that it can be published. Examples of this were certain of the research programs involving strategic plant materials prosecuted during World War II. Among such were the programs involving selections of wild rubber and the search for wild sources of anti-malarials, particularly in the genus *Cinchona*. Several members attending this conference worked on war projects of this type. Unfortunate was the fact that at the conclusion of the war, these programs, including valuable botanical study programs, were dropped and much of the information gathered so laboriously remains in files, unpublished and unknown to the general scientific public. In the case of the two economic groups mentioned, this was the second such endeavor by the government in the same fields, the first being during World War I. In the case of *Cinchona* work, much learned in World War I would have been of great use to the botanists working on the World War II program who had to go over the same ground without information available from the original World War program.

The whole point here is that when a program is initiated on any group of plants, it should be followed through in some way, whether the plant has subsequent value or not. There should be some sort of arrangements with the government whereby programs of this type could be picked up by universities or other research organizations and carried on to their completion. If this is not done, future students in the same field will have to go over problems which

have already been taken care of by past but unpublished research.

Similar to the above problems are those involving Point 4 programs which aid so-called backward areas. Certain of these geographical areas are the great gene centers of many of our economic plants. In the endeavor to improve the status of native peoples with primitive agriculture, highly trained agricultural scientists of our country are introducing high-yielding hybrid varieties of crops which are often so eminently suited to the area that they rapidly replace many primitive native varieties which are subsequently lost. Yet these very same native crop types carry all sorts of important gene characteristics of much value to the modern plant breeder. Concomitant with or before the introduction of modern agricultural races of crop plants to primitive areas should be a collection of primitive varieties for maintenance in germ plasm collections.

A small society could perhaps be headquartered at an institution like the New York Botanical Garden where there is interest in economic botany. Doubtless a good proportion of the membership of such a new society would be from personnel of industry, especially where that industry is concerned with plant utilization. In view of the need for economic botanists to discuss problems with organic chemists and the like, some care should be taken to make certain that annual meetings of any such new society be held in conjunction with both AAAS and AIBS.

DR. DAVID D. KECK

The New York Botanical Garden

It is rather interesting to find that the subject of economic botany has economists and botanists in the minority of those interested in the subject as a whole, which means that the majority is composed of others who are interested in the subject. There is a need for symposia to bring together the various facets of any phase of economic botany, each taking up one subject and discussing it from botanical, chemical, historical, and other points of view, getting interested people together. In order to do that successfully, I think you do need an organization. This is really a synthetic field, the components coming together from various parts of the biological and physical sciences, whereas some other fields are much more natural in that they are composed of closely knit groups. I think that forming an organization to see that groups do come together to express a lively interest in economic botany is going to be a very worthwhile undertaking.

Economic botany expresses something which is often misunderstood, perhaps, but it is important to have the public educated to realize that this is an important subject that can stand on its own feet, without apologies. It seems to me economic botany has a definite intrinsic importance to be recognized.

DR. L. G. NICKELL

Chas. Pfizer and Company, Inc.

Probably the most difficult task we have is to define economic botany if that is the term we want to use. To be economic is really to be practical, but practical is a relative term. Not too long ago, natural dyes were rather important and held a special place in the commercial field. This importance waned as synthetics and coal tars came into general use. Now, with the demonstration of the potential dangers of the coal tar derivations and the threat of their being banned from the market, natural color materials again become important. From a utilization point of view one's interest is in what is important right now. Importance, again, is relative, because what is important now may not be important a few years from now. *Rauwolfia* and

Dioscorea are outstanding examples of some of the factors that are revitalizing the general public's interest in economic botany. From a medicinal point of view, we are becoming increasingly aware of alkaloids, as test methods are perfected. How many of those that we now know exist will become valuable economically? The value is relative. A weed today may become a very important plant from a practical point of view next year.

Medicine is ever changing. Starches, molasses, and corn are used as staples in the production of antibiotics since the microorganisms use them as food. Eli Lilly and Company published in *Chemurgic Digest* the fact that they use two or three million dollars worth of such raw materials a year, as probably does every other firm in the field. The reverse is true for starting materials, for example the sapogenins in a plant. They are not a food; they are the starting nucleus to use in the production of hormones and corticoids. Steroids from sisal and related plants were tried as the starting nucleus in the early work with plant sources as steroidal precursors. The hope was to change the oxygen from the twelve position to the eleven position in several chemical steps under conditions which would be economically feasible. About the time this research was well underway, it was found that certain microorganisms would, in one fermentation step, introduce the oxygen into the desired position. For this reason the nucleus without oxygen in either position was the desirable form. Thus it was found that the Mexican Yam was a more appropriate source, and most producers shifted to this plant.

Concerning publications, I think it would be quite a contribution if more taxonomic papers included in the text information in addition to the taxonomy. I am thinking particularly of analyses of chemical constituents. Such data would be of considerable interest and make these publications of interest to ecologists, plant physiologists, plant chemists, and pharmacologists. An excellent example of this type of work is a recent report by Dr. Alvaro Fernandez-Perez, of the Universidad de Colombia in Bogota. He collected Colombian species of *Rauwolfia* for our company and published results of his collections including a systematic study of the genus in Colombia, a description of the general pharmacology, as well as chemical analyses of the materials determined by our chemists in New York. After all, economic botany in a general sense is not restricted to any one discipline. Botanists have a certain obligation to interest chemists in working with the materials discovered, named, collected, or grown by plant scientists.

In any discussion where funds are mentioned, one keeps hearing the complaint "ear-marked". "This is ear-marked, or that is ear-marked". I think it rather naive and unrealistic to think that no funds will or should be ear-marked. Of course, we would all like unlimited basic research budgets, but we are all aware that this is not possible. However, there are ways to obtain funds which might be very useful to the scientist. It would be ridiculous for a taxonomist who plans a trip to some remote part of the world to collect a restricted group of plants in which he is interested to expect any industrial firm to finance such an expedition. If, in addition, he were to offer to collect plants in which that company is interested, his chances of obtaining funds increase substantially. The latter approach is taken by many, and with a certain degree of success.

One of the continuing problems in teaching is, "How can we arouse interest in botany?" On a broader scale the point comes up, "Someone has to sell botany". I feel very strongly that the teaching of economic botany is one of the answers to this problem. Unfortunately, too many

universities and colleges are not prepared to give such a course. However, this is the type of course that does interest people: young students, the layman, people in business. If they are interested in botany at all, they are interested in the economic side, of botany, not necessarily because they are in business, but because this aspect is appealing to the average person who knows little or nothing about plants. This is true of housewives and businessmen, freshmen and graduate students. Another drawback to teaching is the way it is carried out—often, so dull. To be sure, each type of course has to be taught, but why, for instance in morphology, can't the morphology of the banana plant be included. Most people are extremely interested in a banana plant. They are intrigued with what the plant looks like, how the fruit are borne and the like. This approach is used in other sciences, particularly in geology where it is stressed in introductory courses, a maneuver which lures students who never considered majoring in the field.

As for the starting of a Society for Economic Botany, I believe one of the biggest advantages is the possibility of having in one publication and one meeting a mingling of the disciplines that make up this field. Such an organization would provide a good place for people to find out about the taxonomy of a given plant or group of plants, about the chemistry of these plants, the distribution of the plants, and the feasibility of making them a crop. As for meetings, we might want to consider something in addition to regular meetings as are held by most societies, for example a symposium or invitation type meeting on drug plants or on food crops. Here all aspects of a given segment of economic botany could be discussed. The meeting would not be too large to handle because only those people interested in the plants or topics under discussion would attend. As for membership in such a society from industry, there are not many botanists in industrial research; however, there is a great deal of industrial research that has to do with botany. I feel that many people engaged in this segment of industry would be interested in the formation of such a society which would be the only type of contact which they would like with the botanical field.

DR. CHARLES M. RICK

College of Agriculture,
University of California at Davis

It has been the common experience of plant science departments on our campus that enrollment of undergraduate students is much lower than it should be. At present we could place four to five times as many students as are graduating. The problem of attracting good qualified students in this and other agricultural fields is acute, and solutions are not readily found. Spreading the news in various ways of the favorable employment opportunities does not effectively increase enrollments in our experience. Actually we now have more graduate than undergraduate majors in plant science curricula. Qualified graduate students are somewhat easier to attract, although good opportunities also go begging at this level.

Many reasons probably account for this current lack of interest in economic botany. Partly responsible is the fact that such curricula are not fashionable. Plants are rather fastidious to work with, and other fields require less preparation. Unquestionably primary and secondary education have a great deal to do with it. The decisions of our graduate students as to their field of work were mostly made quite early; rather few admit being much influenced at the college level.

Attractions or inducements at the college level are therefore not likely to be

very effective. Good research assistantships in good universities occasionally are not filled for lack of qualified and interested candidates—a situation unknown 20 years ago. Adding assistantships or fellowships is therefore not likely to assist much in attracting better students to research in economic botany, although it would be a mistake to discredit this type of support. A more effective, though admittedly more difficult solution is to stimulate interest at an earlier age. It is a formidable problem with our present educational system to tamper with subject matter taught in the lower grades. But there are other ways of reaching and influencing these age groups. Unquestionably much can be done outside the school in scouting and other organizations, and we should all shoulder the responsibility of stimulating youngsters by revealing to them the wonders of the plant world.

As to training in economic botany in the broad sense, it is my opinion that most land grant colleges now offer good curricula, particularly at the graduate level. Even for the more restricted concept, students are exposed to much in the way of classification and utilization of crop plants. They usually do not hear much about tropical and exotic crops, but inspired instruction concerning them is not likely to be given by someone not having experience with these species.

The granting of degrees in economic botany does not strike me as being an important or desirable proposal. Until such degrees are well established, they might work to the disadvantage of the recipients. At present many avenues exist for developing thesis problems of an economic botany nature in fields of basic science as taxonomy, plant physiology, ecology, genetics, etc.

Finally, as to support for research and placement opportunities, I feel optimistic. The NSF and other agencies have already granted funds for research in economic botany in the strict sense, and the opportunity is going to improve. Industry is lending support, and future prospects are even more favorable. To meet the predicted swelling of enrollments in the next ten years colleges and universities will have to increase their faculties. For this outlet alone the prospects of suitable placements of new Ph.D.'s with interests in economic botany should further improve.

One aspect of plant uses that understandably is often overlooked is the matter of latent characters. I am referring to the astonishing situation of intrinsic germ plasm of one species that does not gain expression unless transferred to another by hybridization. A case in point is the dominant gene *B*, discovered by Lincoln and Porter in the wild tomato species, *Lycopersicon hirsutum*. This gene, without any known effect whatever in this species, produces a very dramatic change in carotenoid pigments when transferred to *L. esculentum* Mill. Several other instances could be cited from our relatively limited experience with tomato species, indicating that such latent characters are not exceptional. These considerations lead to the disconcerting conclusion that the economic value of a species is not completely understood unless the analysis includes segregating generations of its possible hybrids with other species.

DR. DAVID J. ROGERS

New York Botanical Garden

Economic botany may be considered very broadly as any endeavor which contributes knowledge about plants presently or potentially important to society. Studies of a botanical nature on economic plants should receive the same attention and support from agencies which support purely basic sciences as well as applied sciences. The sad truth is that such is not the case, and reason for this

status is that very little thought has been given to the intent and coverage in the field of economic botany.

It is, then, an important function of this conference to demonstrate the vital role of economic botany in the family of sciences and in the overall society.

Botanical gardens should be at the front in development of economic botany. Actually, the larger gardens, both publicly and privately supported, spend a good part of their budget on plants of importance to man, largely in the area of ornamentals. Such emphasis is important and significant, but there is also need for studies and displays of food, medicinal, fiber, oil, and perfume plants.

Agricultural organizations carry on most of the present studies of economic botany. It is refreshing to see that there is an increase in the number of strictly basic botanical studies being made in experiment stations, but the need for fundamental (or "pure", or "basic") research is still great.

Colleges and universities have promoted economic botany to some extent. Probably the most successful, the oldest, and best considered program in economic botany has been at Harvard University. However, the majority of institutions for higher education in this country pay only lip-service to this area.

Studies in economic botany must be a cooperation among many disciplines. As an example, the classification of variation of economic species can only be accomplished when agricultural institutions are willing to grow the numerous variants in test plots which have been expertly cared for by agronomists, and genetic studies of these variants are best accomplished at the time that the taxonomist is making herbarium material for systematic studies. The chemical analyses of the variants must likewise be set up at the time of growth of the plants. This is an ideal which can rarely be accomplished for any group of plants and is beyond possibility for studies of certain economic species, but even the most prominent of the crop plants have seldom been so treated. Our tropical cultivars are in particular need of fundamental research.

Researches in economic botany are generally no more expensive than any others, but little support has been forthcoming for the pure types of research. There are exceptions both from privately and from publicly supported agencies, but not enough to be of significance.

Mention has been made of the fine program at Harvard in both research and education for economic botany. The success of the program there should point to the type of program which would insure a continuing supply of superbly trained botanists whose endeavors are largely in this field. A look at the background of our conferees will show that Harvard's program has been an outstanding success, for a good proportion here are from that school.

I think that there must be a recognition that the fundamentals of botanical sciences provide the backbone for training in economic botany. The only significant difference between Harvard's program and that of many other institutions is the conscious and consistent emphasis on studies of plants important to man. No program for a degree in economic botany will be as successful as a program which has been well defined in botany generally, whether it be physiologic, ecologic, taxonomic, or other.

One important aspect must be raised in this connection. Botanists are not numerous because of the difficulty of finding jobs in other than academic settings, largely because they are consciously labelled as botanists. The important point, therefore, is the education not of the botanists, but of employers who must some way learn that the botanist can contribute as well as or better than students in other disciplines to the

study of useful plants. There are many problems involved in an education program for administrators, but something has to be done, from within the field of botany and outside, to impress the public at large with the need for more botanists working in economic botany.

In order to solve some of the problems discussed above, some common meeting ground for interested individuals must be provided. There are many societies, clubs, or other such organizations in existence whose purpose is the dissemination of knowledge. These are frequently organized around a single science or discipline within a particular science and limit the participating members to those well versed in that area.

There is, therefore, a need for an organization or society for economic botanists which has a different orientation. Since economic botanists are from many different disciplines, the focus for a new society must be a unifying one, oriented to fit needs not now filled. If such an organization can be properly defined to accomplish this unification, it will find a place in the general society of science.

DR. RICHARD EVANS SCHULTES
The Botanical Museum, Harvard University

It would be my hope that this conference on economic botany could avoid becoming unduly preoccupied over definitions. There is no word or term which will not cause trouble when one starts to define it. Economic botany is quite patently a blanket term signifying many facets of the study of plants as they touch human life. For purposes of discussion here and for any considerations connected with the possible formation of a society, I believe that the very broadest significance should be welcomed.

At Harvard, the oldest course in economic botany in this country, given without interruption since 1875, is called "Plants and Human Affairs". It includes what some people like to split off as a separate discipline under the name ethnobotany—the relationship between plants and primitive man today and, through the study of archaeological remains, of past ages. But, in the final analysis, there is no way of separating the relationship between plants and *primitive* men from that which exists now between plants and *highly advanced* man.

From an academic point of view, the all-important goal must be to provide the man—whether he be concentrating in the biological sciences, anthropology or geography—a well-rounded and perhaps not-too-detailed understanding of how and why man is still dependent on the Plant Kingdom, even though, year by year, in a complex civilization like ours, he is farther and farther removed from plants because of intermediate processing. In the academic sense, it is essential to set out primarily *not* to prepare students merely for filling a specific job in agriculture or industry. The man who is well-trained in the fundamentals and who has been provided with a broad, interdisciplinary outlook, will eventually fit in and be better able to cope with the specific jobs. I cannot stress too strongly how important it is for us to avoid being stampeded into training a large number of men who, though prepared to do routinely a particular job in economic botany—in a drug company, for example—are really not truly educated in their field.

Another consideration which a conference like this one of ours should discuss, I believe, is emphasis on field work. It is certain that many of the greatest discoveries in economic botany lie awaiting us in the field. Reliance upon medicinal and other plants is fast disappearing among many primitive peoples with the advance of modern civilization. Special training of a botanical nature must underlie good field work in economic botany. Much of the truly outstanding

chemical research done in the past on native medicinal plants is of no value because the material analyzed was not properly identified with voucher-specimens in herbaria and cannot be repeated.

Certainly in botany today there is no dearth of talking. Much, if not most, of the money used for congresses, symposia, conferences, and colloquia could perhaps, if we consider the advancement of our science, better be diverted to the preparation and sending out of young men to do research. Perhaps, after all, our problem may not be where to get sufficient financial support but how we can exert pressure that the funds we do get are most advantageously spent.

Those who are interested in research in economic botany are keenly aware of the need for constancy of organization and of support. Research in this field usually, by its nature, stretches over a long period. Changes and sudden withdrawal of support short of a goal often happens in government-sponsored programs of research. During and after the recent war, I worked on the rubber program directed under a modest budget by scientists in the Bureau of Plant Industry. Shortly after the war, this program fell under the direction of one of the new technical aid organizations of the government. Scientists no longer directed the work. The new directors could not understand the need for basic research and gradually eliminated practically all of the scientific aspect of the undertaking. One of the most important contributions we as economic botanists may be able to make, perhaps, will be to exert pressure, individually and through our institutions and societies, to enforce constancy and continuity on the part of governmental and other agencies supporting basic research in the field.

It seems stranger to me every day that, in this stage of history which is witnessing a shrinking world, the American universities offering instruction in tropical botany can well be counted on one hand. There are plans by American universities to set up still more stations in the tropics when those tropical academic and research institutions in the New World are not nearly fully utilized and when a number of them can hardly exist financially. This is a tremendously confused picture that we see, and perhaps as economic botanists gathered to discuss the aims of the field we might well try to offer some guidance. Should we really seriously attempt to extend work in economic botany without first or, at least, concurrently implementing our instruction and training in tropical botany? With so much of our future opportunities in the tropics, are we not sending out our young men in economic botany without adequate training in view of the desert of instruction in tropical botany with which they are faced in our schools?

This, of course, leads us rather abruptly to take a look at training in biology, at least, in botany in the secondary schools. Few people would deny that public school education in this country is sliding dangerously. A large part of the loss in quality and quantity of education in the secondary level may be precisely in the insufficient attention paid to the sciences. Here we find that biology, more especially the botanical side of biology, has virtually disappeared from a substantial portion of our public high schools. It would appear to me that botany might well be reintroduced to our high schools with a distinct flavor of economic botany, thus bringing to the student's attention the impact of plants and their biology upon man himself. This approach would seem to me to be one which those of us working in economic botany in academic or research institutions or in museums or gardens might stress for the benefit of future crops of scientists.

There really *is* a public awakening in botany—especially in the various branches of economic botany. Never

before in history have so many people subscribed to horticultural journals or belonged to so many horticultural or gardening societies. Our museums have never opened their doors to more visitors. If, as some educators insist, there is no interest in botany, it certainly is not true of the general public, of industry, of medical sciences, or of governmental agencies.

As to the advisability of founding a Society of Economic Botany, there are several considerations of importance. Would it be just another society or association to join? What are the real needs for forming such a group? How inclusive or exclusive would it be?

Personally, I would not hesitate to join such a society if it stood for something and published tracts or a journal. There is a need for such a group in a discipline which is so loosely knit in interests. However, it must foster rather an inclusive membership. I do not believe that such a society should be appendaged to any of the existing associations, such as the AIBS—certainly not at first.

This meeting has pleased me mostly for one reason. Dr. Keck has said that it has shown that economic botany can stand on its own feet. A large number of us here are or have been more or less directly working in pure sciences, and we well know that the differentiation of pure and applied sciences is still very much with us. It is rather gratifying to see that, through the years, universities, botanical gardens, and the Bureau of Plant Industry itself have come to realize that economic botany is in reality a field of and sometimes by itself. And I think that if the proposed Society for Economic Botany be formed and takes over ECONOMIC BOTANY or strengthens it in any way this would constitute another step forward for economic botany not only in industry but in agriculture and teaching. If only pointing up the existence of this field, this conference, I think, has fulfilled a very good purpose.

DR. G. LEDYARD STEBBINS

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Except in connection with curricula in agriculture, forestry, and other applied fields, botany has always been a subject in which relatively few people have become interested, and there is no reason to suppose that this situation is likely to change in the future. In the development of professional botanists, therefore, the wisest approach is not a mass appeal through large introductory courses taught brilliantly by outstanding teachers, or through emphasis on the economic advantages offered by a career in plant science. The potential leader in plant science is much more likely to be found by developing ways of establishing individual contacts between outstanding young people who are interested in our field and practicing botanists whose eminence and research ability is matched by their skill and ability in stimulating young minds on an individual basis. The New York Botanical Garden could serve as an intermediary in such activity through the presence on its staff of one or more educators with a thorough knowledge of and enthusiasm for plant science, who could communicate freely and intelligently with high school students on the one hand, and the research staff of the Garden on the other. The function of these educators would be to organize and conduct visits of school children to the Garden, and on such visits to make contact as much as possible with individual students who showed an unusual interest in and aptitude for plant science. This interest could be further encouraged by guiding the young person in small research projects, either directly or through advice given to his school teacher.

Another way in which the Garden can help develop interest in plant science is by emphasis on special exhibits of plants which are useful or otherwise interesting to man, such as the origin of certain crop plants or ornamental flowers. Exhibits of this sort have to be planned with the greatest care and must present information derived from all branches of plant science, particularly genetics, cytology, and morphology, in addition to taxonomy. When well done, they present to intelligent young people as clearly as possible the interest which may be derived from a study of cultivated and other economic plants.

For students whose interest is aroused and whose ability is demonstrated, the Garden can provide better educational opportunities by establishment of endowed fellowships, which will enable students to do research under the direction of Garden staff members. One suggestion in this connection is that competition or overlap with the research activities of the U.S.D.A. and the State Experiment Stations will be best avoided by establishing projects and opportunities dealing not with the major crop plants, such as corn, wheat, cotton, and tobacco, but with plants which are less extensively studied by the agricultural research stations, such as drug and oil plants and the garden ornamentals.

Research activity in economic botany should emphasize not only the specific uses of economic plants, but also their relationships and origin. For the latter purposes the synthetic approach is essential. Information from systematics should be combined with that from genetics, cytology, and morphology in an intelligent fashion either by a single person well versed in all of these disciplines, or by cooperation between botanists who, though in different disciplines, nevertheless thoroughly understand each other's point of view.

A useful aid to research in which the New York Botanical Garden might take an active part would be the establishment of "gene banks" containing little used strains and wild relatives of the more extensively cultivated economic plants. These would provide valuable sources of genes for plant breeders. "Seed banks" of this sort have already been established by the U.S.D.A., but the more difficult task of maintaining "nursery banks" of perennial and woody plants, particularly of tropical species, has not been undertaken on a large scale as yet. The Garden can aid such projects by helping to raise funds for them, and by using the services of some of its staff members for their planning and maintenance.

Before conclusive steps are taken toward the development of a Society of Economic Botany, a careful questionnaire poll of prospective members should be made to find out what type of journal-society arrangements would receive the greatest support.

DR. CHARLES TODD

Du Pont Experimental Station

If one is to recruit good students for the botanical sciences, the place to start is in the high schools. This is not an original thought. Other groups of scientists are also concerned about where they are going to find capable students and are now focusing their attention on the high schools. Thus competition for students is getting keener.

Botany is an excellent science course for high schools because it provides a way of teaching basic principles of biology that will be important and useful both to students going on for advanced training in science and to those who are not. This latter group is almost certain to have a continued contact with botany throughout their lives on farms or around their homes in raising lawns, trees, shrubs,

and ornamental flowers. Thus, the first thing should be to encourage the teaching of botany in high schools to a greater extent than is now being done. Since the value of the course will bear a direct relation to the interest and knowledge of the individual presenting it, consideration should be given to ways of getting more botanists teaching botany in high schools.

Once the student's interest has been aroused in high school, the task has only begun. This interest must be preserved through proper instruction in the university, particularly at the undergraduate level. Undergraduate instruction in universities is frequently neglected by potentially capable teachers because their primary interest lies in research. Teaching of the undergraduate is not a chore to be relegated to the new instructor who is unable to avoid it.

In summary, to assure a supply of topnotch botanists in the future, first of all, you have got to arouse the interest of the student in high school, and then you have to preserve and develop this interest after the student gets into college.

BOOK REVIEW

Control of the Plant Environment. Edited by J. P. Hudson, Department of Horticulture, School of Agriculture, University of Nottingham. Academic Press, Inc., New York, N. Y. xvi + 200 pp. Price $7.50.

This book is an edited transcript of the papers presented and of the discussions which took place at the Fourth Easter School in Agricultural Science at Sutton Bonnington, England, under the auspices of the University of Nottingham School of Agriculture.

The Fourth Easter School considered the control of the plant environment in both its technical and biological aspects, an ambitious project demanding the contributions of specialists from widely varying disciplines. It represented a praiseworthy attempt to collect together exponents of each group and fully explore both the potentialities and limitations of plant growth studies in a controlled environment. This volume shows how successful the meeting was and contains a great deal of information of value to workers in the field. Further, the book offers much to the uninitiated reader desiring to gain an up-to-date picture of the possibilities of environment control.

The volume is divided into four sections. The first part deals with the general relationship between the plant and its environment and discusses the value of controlling the environment in genetic studies. The variables emphasized are air and soil temperatures, light, vapor pressure and composition of the air, the effect of wind and the availability of soil moisture. In addition to reporting results already obtained, the contributors show no hesitancy in critically evaluating the difficulties and limitations in controlled environment studies. The greatest single difficulty which becomes apparent is that there is no such thing as a "neutral" environment to which plants do not react at all and which would, therefore, serve as a convenient reference point. The section is concluded by a paper which considers the use of a greater degree of environmental control in crop husbandry, an aspect uppermost in the minds of agricultural scientists.

The second part comprises three chapters. The first of these deals with plant responses to soil moisture and discusses methods of maintaining and assessing soil moisture. It also reviews the concept of the water regime and its potentialities in experimental work. Following this is a consideration of successful glasshouse design and the place of the glasshouse in controlled environment studies.

The remainder of Part II is devoted to an authoritative exposition on growth room design, and to the research worker this chapter may well be very valuable. The practical consideration of cost is a very valuable inclusion!

Part III opens with a general discussion of the uses to which a controlled environment may be put together with a consideration of the interrelationship between the type of control required and the types of studies to be made. This is followed by a series of descriptions of actual working installations of various kinds. They include an account of a Phytotron and its system of management and range through growth rooms and growth cabinets, culminating with a brief description of tunnels devised to study wind effects on plants. All these sketches are helpful in illustrating what has already been achieved in the design of environmental control apparatus for different kinds of work, and with varying financial resources.

The final and perhaps least successful section of the book is devoted to abstracts of demonstrations which formed part of the symposium. A number of these were obviously meant to be complementary to the demonstration and thus are not very meaningful when considered alone. However, the

section includes a short chapter, "Lamps for use in controlled environment", which contains data on the spectral flux distribution of both tubular fluorescent lamps and four types of higher powered discharge lamps.

This admirable production is completed by a list of members and both Author and Subject indexes, as well as Definitions of Terms. It may be fairly said that the Fourth Easter School in Nottingham was successful, both in promoting knowledge and arousing interest.

ALAN J. THOMAS
The New York Botanical Garden